MICROMETERS

SLIDE GAUGES & CALIPERS

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Slide Gauges and Calipers

Principles, construction, operation and use of appliances for fine mechanical measurements

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PREFACE

As everyone fully realises, great strides have been made in the progress of engineering practice in recent years, and improvement is still going on. Apart from the steady improvement in design, and in the materials available, the most important factor in engineering progress is accuracy, and it is quite true to say that modern achievements in the performance of engines and machines can largely be explained by the fact that they are constructed and fitted to very much finer limits than those of but a few years ago.

No mechanic, however skilful, can work to a higher accuracy than that of his measuring instruments, and it has thus been necessary for the latter to keep pace with developments ; the use of precision instruments has also been greatly extended, and whereas many engineering works, in former years, kept only one or two micrometers for use in the tool room, nowadays it would be quite impossible to carry on without the constant use of micrometers in the hands of every skilled worker.

This book does not presume to be a scientific treatise on measuring instruments or their application ; it is written in simple language for the instruction of practical workers who have an intelligent interest in these instruments, and wish to use them to the very best advantage. Neither is it intended to be in any sense a substitute for the skill acquired by practical experience, but it is hoped that it will serve as a useful introduction to the use of the instruments concerned, and in this way will help the worker to attain such skill.

In the preparation of this fully revised and enlarged edition, account has been taken of all modern developments in engineering practice and the design of instruments, and close consideration given to the criticisms—happily very few—which have been made on minor details of the original work. There is ample evidence that the earlier types of instruments are still in extensive use, and it has been considered better to retain matter which may be superfluous than to risk leaving a void in the subjects that should properly be covered.

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INTRODUCTION

PRINCIPLES OF ENGINEERING MEASURING INSTRUMENTS

THE instruments used for dimensional measurement in engineering practice may be grouped in two main classes, namely, direct registering instruments, and comparators. The former are invariably equipped with some form of graduated scale, which indicates the size of the object to which they are applied, while the latter are not so equipped, but must be set by reference to a scale or master gauge, and used to compare the dimensions of the work with this standard dimension. It is, however, always possible to use a registering instrument as a comparator, and many instruments primarily designed as comparators may be elaborated by the addition of a registering scale.

The Micrometer

The micrometer, in any of its forms as used by engineers, is essentially a registering instrument, and the principle of its operation involves the use of a screw thread, which not only improves its sensitivity of control, but also simplifies the problem of registering very fine measurements, as it is possible to use two separate scales, one recording complete revolutions of the screw (each of which registers a dimension equal to the pitch of the screw) and the other, the finer dimensions equivalent to parts of a revolution. The screw thread may be defined as a continuous inclined plane which, in effect, multiplies the spacing of the graduated scale or scales, and not only makes them easier to read, but

also minimises error. Theoretically, there is no limit to the degree of accuracy which can be attained by a micrometer, but practical considerations, one of the most important of which is the effect of expansion and contraction under varying temperature, restrict the application of the ordinary micrometer to the measurement of minimum limits of about one ten-thousandth of an inch, or one four-hundredth of a millimetre.

The Slide Gauge

Slide gauges are generally, but not necessarily, registering instruments, being usually provided with a graduated scale which is identical to that of an ordinary fractional-inch or metric rule. The movable element of the gauge carries a zero mark or pointer, by means of which the size is read against the scale. In order to facilitate the reading of fine measurements, slide gauges are commonly equipped with a vernier scale on the moving part. It is emphasised, however, that the vernier scale is neither an essential feature of the slide gauge, nor yet exclusive to it, as it can be applied to any measuring device, and is extensively used on protractors, height gauges, and also micrometers.

Calipers and Fixed Gauges

Simple calipers are essentially comparators, but as will be seen, they can be, and often are, fitted with registering scales.

Fixed gauges, including plug, ring, slip, feeler or other forms of limit or reference gauges, are outside the scope of this handbook, but the information on the general science of fine measurement contained herein will be found helpful also to users of such gauges.

CHAPTER I

SIMPLE AND REGISTERING CALIPERS

THE simple or " firm joint " caliper shown in fig. 1 was, in the early days of engineering, the most extensively used instrument for external and internal measurement, but its use for really important work is not encouraged in modern practice. Such calipers have a riveted or bolted joint with friction washers set up sufficiently tightly to prevent inadvertent movement, and are adjusted roughly by hand, fine adjustments being made by tapping either the limb or the pivot on some solid object, to close or open the points respectively. The setting is obtained by reference to a scale or a gauge piece, and a fair amount of skill is necessary both in setting the instrument and in using it, as the accuracy is dependent on sensitivity of touch. Although the crudity of the means of adjustment is a great disadvantage, the old-time craftsman succeeded in working to fairly close, though undefined limits with simple calipers.

Spring Calipers

Several types of spring calipers have been devised, including one-piece instruments constructed similarly to a draughtsman's spring bows, but the most popular type in present use employs a separate spring of almost completely circular shape to actuate the legs, as in the examples shown in figs. 2 and 3. The legs are rigid, and entirely separate from the pivot joint, the latter being made by a reel-shaped pin—shown in the section—which fits into semicircular grooves cut in the inner sides of the ends of the legs, and upon which

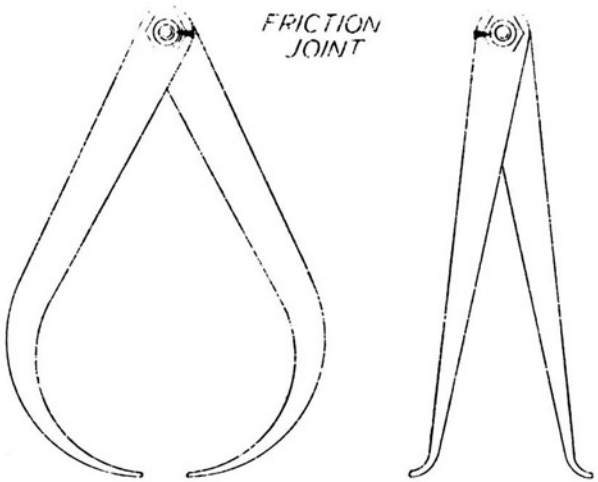

Fig. 1.—Outside and inside firm joint calipers

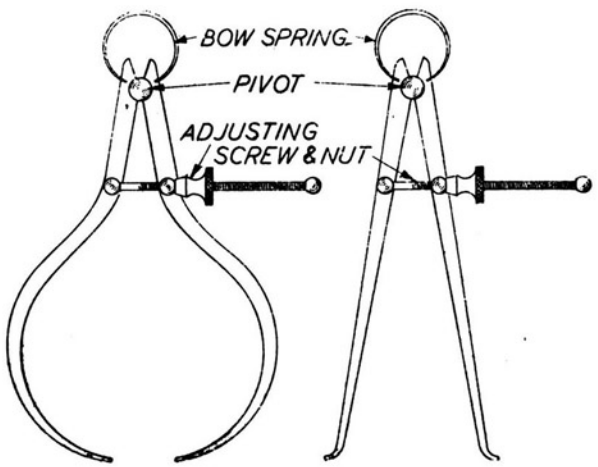

Fig. 2.—Outside and inside spring calipers

they are free to rotate relatively to each other, being limited in their movements outwards by their projecting ends coming in contact. They are controlled in this same direction by the bow-shaped spring A, the ends of which fit into grooves upon the outside of the legs above the joint. When

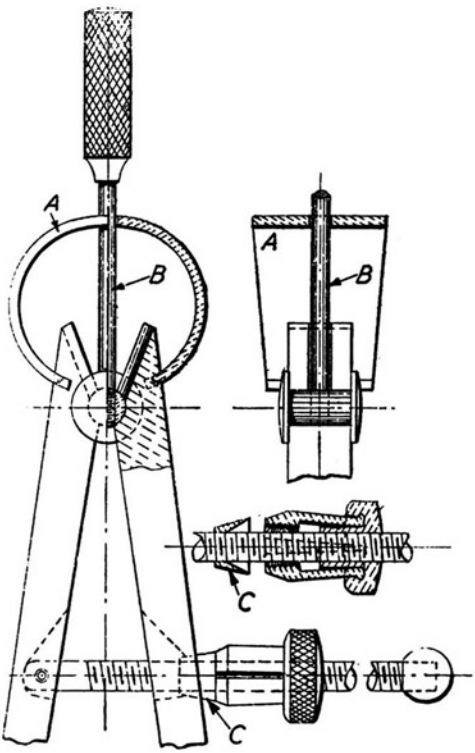

Fig. 3.—An improved form of spring dividers, incorporating a self-centring head and a quick-release adjustment nut

the legs are wide open, the tension on this spring is then sufficiently strong to prevent its coming out of its place. It will be seen that by the controlling action of the nut on the adjusting screw below the legs can be drawn together or allowed to part, being kept taut by the action of this spring.

The advantage of this form of joint is that, being made up in separate parts, should the spring fly, through rapid change of temperature or other cause, it can be replaced without discarding the other parts of the tool. The vertical pin B, together with the knurled handle at the top, are provided for actuating the dividers more conveniently. A further ingenious attachment to this form of tool is the quick-action split nut shown in section in the same figure. Here the compression, in any position, brought about by the spring causes the taper collar C to clench the nose of the split nut and so to lock the threaded portion on to the adjusting screw. If the calipers or dividers are at a small dimension, they can be set nearer their full extent by releasing the tension on the spring by gripping the legs together in the hand ; the nut can be split and drawn over as many threads as necessary. The legs are then allowed to spring out, take up the compression, and lock the nut on that point, after which the fine adjustment can be made in the ordinary way. The rapid adjustment is, of course, equally useful in either direction. The small internally threaded knob, shown on the end of the screw, is to act as a stop to prevent the nut leaving the thread entirely.

Spring calipers are very much easier to adjust than the firm joint type, and have practically superseded the latter in modern practice ; but the same considerations apply in respect of sensitivity of touch in using them. This feature is liable to introduce some difficulty, in cases where measurements made by one operator have to be transferred to the hands of others, as the sense of touch, like other human senses, is entirely individual and is not identical in any two persons. In modern manufacturing processes, therefore, where operations on mating components are handled by different operators, the use of calipers is usually discarded in favour of measuring devices which eliminate the human element.

In addition to outside and inside calipers may be mentioned

the " hermaphrodite " type, which is constructed with limbs extended on either side of the pivot joint, so that as one pair closes, the other opens. These calipers thus give inside and outside measurements simultaneously, but although in theory this is a great advantage, the practical use of such instruments is limited by the possibility of inherent errors, and they are not much in favour nowadays.

Dividers

Dividers may be defined as a form of caliper used for measurement between points, instead of inside or outside

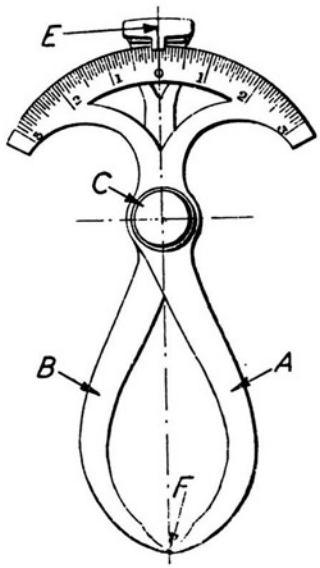

Fig. 4.—Registering calipers, graduated for inch measurements on one side. The reverse side may be marked with a metric scale

surfaces. Any of these instruments may be of the firm joint or spring type.

The addition of registering devices to calipers, by means of which the set size of the measuring points is recorded upon a scale, forms a very useful combination. Fig. 4 is an example

of the best form of this kind of caliper, and it will here be noted that the scale is divided upon a quadrant arm attached to the leg A. The index pointer is actuated by the leg B, and, as will be seen, records its reading upon either side of the zero mark to give both external and internal readings. For the latter, it is necessary to spring the legs one over the other, and they are of such a form that comparatively small internal dimensions can be taken by this means. Now it may occur to the reader that the construction of such as these is quite a simple matter. Offhand it appears that the quadrant scale is merely dividing out into a number of equal divisions marked inches, the proportion of which to the measurement made by the legs of the instruments is the relationship between the radius C E and the radius C F. As a matter of fact this is only correct when the caliper stands at zero, for it must be remembered that the measurement made by the points is along the chord of the circle described by the radius C F; therefore the measurements shown upon the scale above are in proportion to the chords of the arc through which the index moves to record that size; consequently the length of the succeeding divisions continually increases, measured along the arc, which fact can clearly be seen by referring to fig. 4.

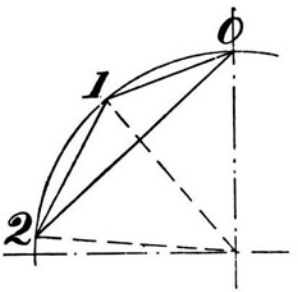

Fig. 5. — Diagram showing proportions in marking a registering caliper

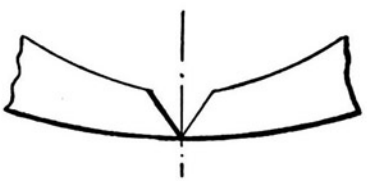

Fig. 6.—Best type of points for registering calipers

Referring to fig. 5, which is a diagram showing a portion of the quadrant scale, as an arc, the point marked 0 being zero, if we move the index through the distance 1, the

chord 1-0 has a length in proportion to the varying radii of the calipers. Now, if we take a chord of double this length, which reaches to point 2 upon the arc described, it may seem at first that the arc 2-0 should be exactly double the arc 1-0, but if this were so, it would be equivalent to proving that two sides of a triangle are equal to the third side, which we know to be wrong. Therefore, the chord 2-1 must be longer than the chord 1-0, and the corresponding arc 2-1 must be much greater than the arc 1-0, but the calipers in passing through the spaces described will only be making twice the

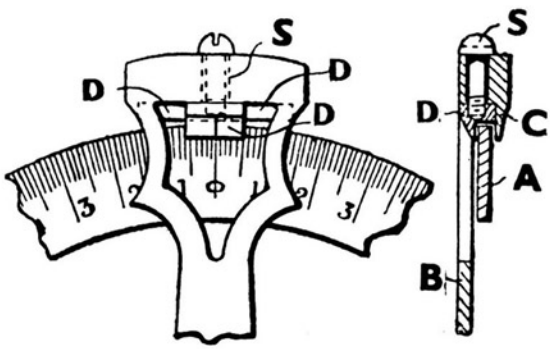

Fig. 7.—An adjustable index fitted to registering calipers

measurement. From this it will be seen that the graduation of a pair of calipers of this class is a matter involving the use of very accurate geometrical dividing devices.

It is usual for the manufacturers to finish off the points of calipers rounded, the idea of this being to allow for the extreme wear to which they are generally subjected ; but in the case of registering calipers, an element of inaccuracy creeps in, in proportion to the size of the point, which renders it absolutely necessary to have as sharp measuring points as are consistent with strength.

It is essential, in cases where extreme accuracy is desired, to alter the points to the form shown in fig. 6, in which the measuring point approaches as nearly as possible to a knife

edge, but it is necessary, in view of their limited area to see that they are thoroughly hardened to resist wear.

Calipers of this description can be obtained very cheaply; it can be taken for granted that their scale is accurately set out, and it only remains to set the points as described above.

Setting the Point

This is the method. Having thoroughly annealed the points, file them to the shape shown in fig. 6, taking care to remove no more metal than is absolutely necessary ; now close the calipers, give them a slight tap to be sure that they are well together, and examine the points to see that one is not longer than the other. If found to be so, by opening the calipers wide and placing the longer leg in the jaw of the vice (being careful to use lead clamps) a smart blow upon the point with a small lead mallet, or, better still, a hardwood drift, will usually set it sufficiently to correct any error of this sort. Having closed the points again, the first thing to see is that the index is upon zero of the inch scale. If it is not so, by gripping the leg carrying the index pointer between the jaws of the vice, the pointer can be set over by using a wood drift placed upon the side of the index frame, and giving it a tap with a light hammer in the necessary direction. This does not in any way affect the set of the points. Now it is necessary to use a standard gauge, which should be as near the maximum reading of the scale as possible : in the case of fig. 4, say a 2 in. or 2½ in. male gauge. By carefully setting the points to this gauge, any inaccuracy in the radial length of the measuring arms now becomes apparent, in that, if the legs are too long, the index will record under the size, and if too short, the contrary will be the case. Care must be taken in lengthening or shortening the legs—which can be done by means of the wooden drift, as described before—that, when closed, they are both of the same length and the measuring edges shut together exactly. This operation is almost sure to take the index off the zero again, which will have to be

corrected before testing the legs again on the standard gauge. Usually three or four operations of this sort are sufficient to determine the length of the legs. Having adjusted the caliper to these limits, it is only necessary to harden the points.

The form of registering caliper which we have had under consideration is usually engraved with a metric scale in centimetres and millimetres upon the reverse side of the

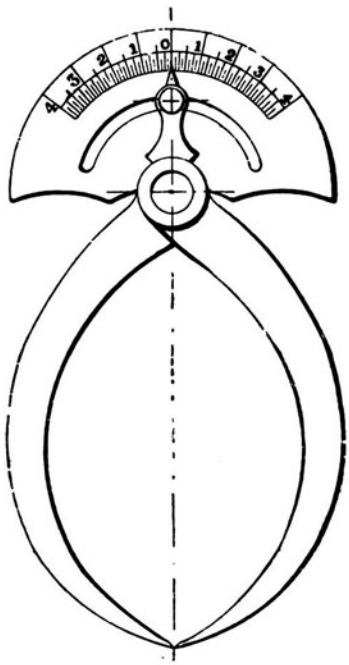

Fig. 8.—English type of registering caliper

quadrant to that of the inch, entailing the use of a separate index, which is generally fixed.

A very good addition, but one involving much work, is to remove the fixed index pointer on the metre scale and replace it by one adjustable, slightly lateral, as it will often be found that both indexes are not on their respective zeros simultaneously. If the zeros of the scales do not coincide and the indexes do, or *vice versa*, one scale is always out of calibre.

Now, it is rather an unsatisfactory job to try to re-engrave an index, but the addition of an adjustable index on either side serves the purpose and is far more accurate. Fig. 7 is a full-size elevation and section of the metric index, which in this case is a movable pointer. Referring to the section, A is the quadrant, B the index arm, C the fixed index on the inch side, and D the adjustable index on the metric scale. The arms D′D′, shown on the elevation, are one with the adjus-

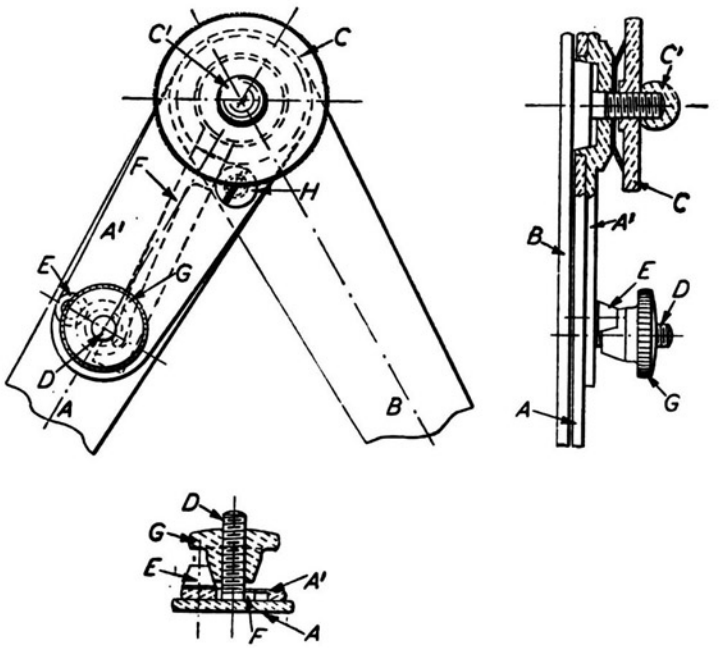

Fig. 9.—The Starrett locking and fine adjustment device

table index and lend it rigidity. The fixing screw is shown at S, and the oval clearance hole—to allow of the movement of the pointer—is shown dotted at S′. The play in this hole need not exceed a total of $\frac{1}{32}$ in.

Fig. 8 is a design of the form of caliper last described made by a well-known English firm, the quadrant scale being engraved on a plate, while the index is a hand or pointer

travelling below it. These are constructed so as to be clamped rigidly on any point.

Recent Improvements

Of recent years several American firms have turned their attention to improving ordinary workshop calipers and notably among these the L. S. Starrett Company, of Athol, Mass., U.S.A., have made rapid strides, and have produced several ingenious devices. Referring to fig. 9, which is an elevation and sections of the joint and adjusting device of a

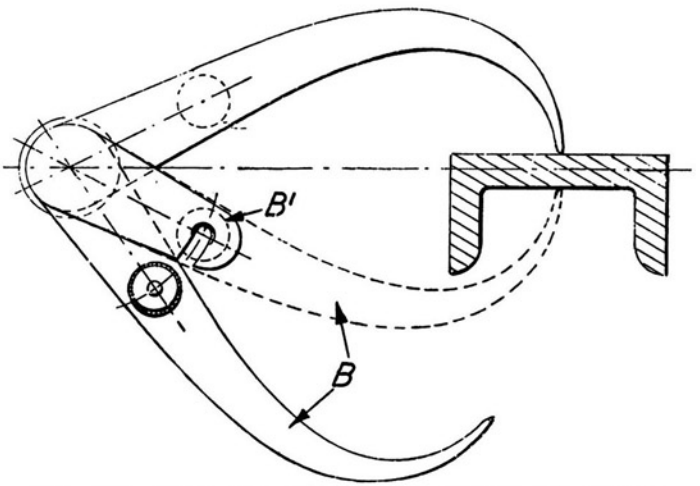

Fig. 10.—Starrett caliper with detachable leg to allow of withdrawal

pair of calipers in which A and B are the stumps of the legs, it will be seen by looking at the section that the leg B is in one with a tapered boss and screwed stud, and that the leg A is free to revolve upon the internal boss of a false leg A'. This latter is bored out to the same taper as the fixed boss upon the leg B, and normally rides upon it. Upon the outer end of the screwed stud is shown a milled nut C, which, when screwed up against the face of the projecting part of the false leg A', causes it to seize tightly upon the adjacent portion of the leg B, and so lock A' to B. When the nut is

out to its full extent—which is limited by an internal screwed knob C′ on the end of the stud—sufficient pressure is put upon the joint by means of a light steel spring shown between C and A′, to cause the joint to hold together. The reason for making leg A separate from the locking device is to permit of finely adjusting it relatively to B, which is done by the following method. Upon A is fixed a screwed stud D

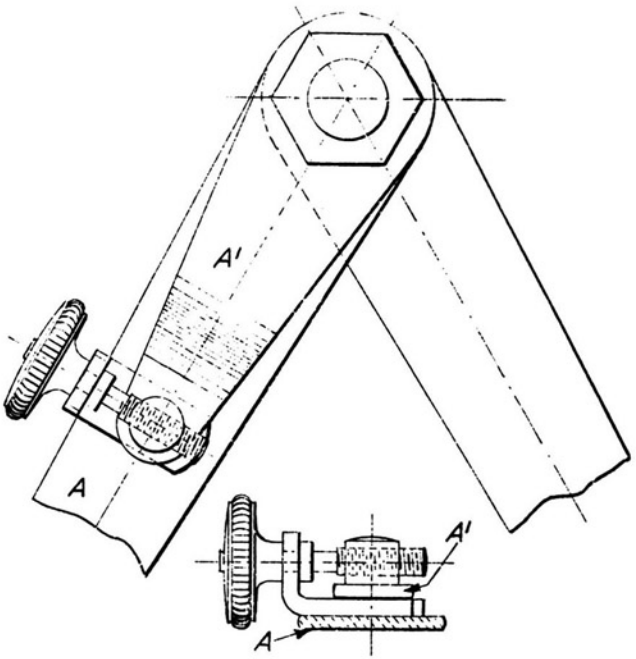

Fig. 11.—Another type of Starrett fine adjustment device

which passes through a hole in A′, having plenty of clearance to allow of A moving relatively to A′. Upon the side of this opening on A′ is fixed a small steel cone E, against which ordinarily the stud D is pressed, by reason of a strong finger spring let into the underside of A′ and shown dotted at F. The action of this spring practically makes A solid with A′, while a setscrew with flat head H screwed into A keeps the two pieces in close proximity.

If now it is intended to close the caliper leg slightly to finely adjust the points, by screwing down the cone-shaped milled nut G until it comes in contact with the cone E, the forcing action brought about against the cone will cause A to move relatively to A′, and by unscrewing G the spring takes up the action and opens the leg out again. This constitutes the fine adjustment on the best class of caliper made by the Starrett Company. It will be seen that the advantage of this device does away entirely with the old method of tapping the caliper legs on a bar to close them slightly, or on the butt of the joint of a flat surface to open them again. In conjunction with these calipers a further device remarkable for its extreme simplicity is added, which fig. 10 shows so clearly that scarcely any description is necessary. The leg corresponding to B in fig. 9 has a false leg B′, which is attached directly to the locking device, leaving the main leg B free to open out. B is normally locked to B′ by a stud passing into a slot in the latter with a tapered nut, similar to the one shown on the fine adjustment device, which beds itself into a countersunk opening at the end of the slot. Having taken the measurement of the web of a channel or casting similar to that shown in fig. 10—from which it will be seen that ordinary calipers cannot be withdrawn—by unscrewing the nut and allowing the point to clear the groove, the leg B can be opened and the caliper removed, after which, by replacing it and locking as before, the measurement can be read off. Fig. 11 shows a type of fine adjustment which is a somewhat older device, and is generally added to the form of caliper drawn, viz. such as have no locking attachment. Here the false leg A′ carries upon its end a traversely tapped stud which travels upon a similar traversing screw controlled by the milled head, which, with its bearing, is part of the leg A. The hexagon washer shown on the joint is provided to allow adjusting the joint to the required degree of friction. This latter joint is similar to the locking joint shown in fig. 9.

CHAPTER II
SLIDE GAUGES

THE most simple form of slide caliper is that shown in fig. 12. The object to be measured is placed between the jaws, the sliding one being moved along the bar until it touches the object ; on this jaw is either a line or a thin edge which moves over the graduated lines marked on the bar. The size of the object between the jaws is known by reading the line on the bar which is opposite the mark or edge on the sliding jaw.

Fig. 13 shows a caliper reading 2 in. between the jaws, the size being indicated by the fine edge on the movable jaw.

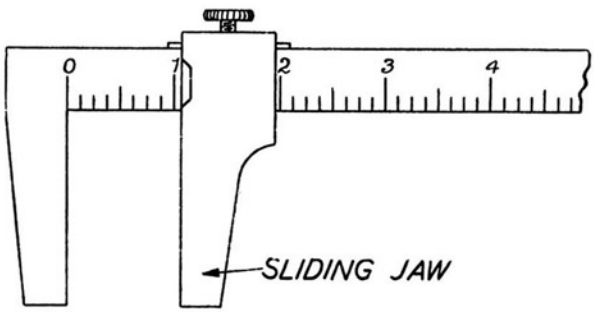

Fig. 12.—A simple form of slide gauge

Fig. 14 shows a similar caliper, also reading 2 in. between the jaws, the size being indicated by the outside mark on the movable jaw. This caliper is also arranged to measure the diameter of holes ; its jaws are therefore provided with projections (P, P) to go inside the hole to be measured. As these projections must have a certain thickness, it will be seen that the mark on the movable jaw to indicate the size of the hole

cannot be in the same position as the mark which indicates the size of objects placed between the jaws ; a second mark is therefore provided, which will be opposite the mark on the bar corresponding to the width of the projections P, P when

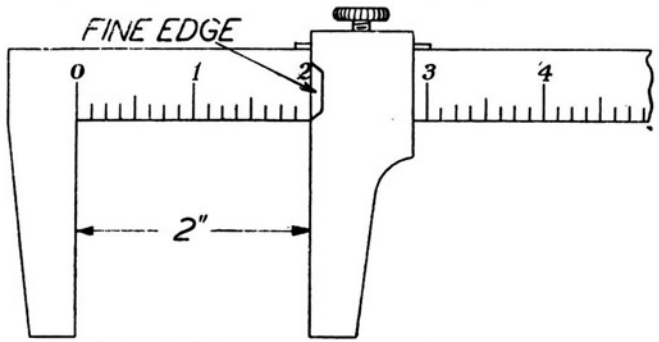

Fig. 13.—Simple slide gauge opened to a width of 2 in.

the jaws are completely closed. It does not matter at what part of the bar the graduated line commences, as this will depend upon the position of the edge or line on the movable bar which is used for reading off the size indicated by the caliper. In fig. 13 this edge happens to be in a straight line with the measuring part of the movable jaw, and the lines

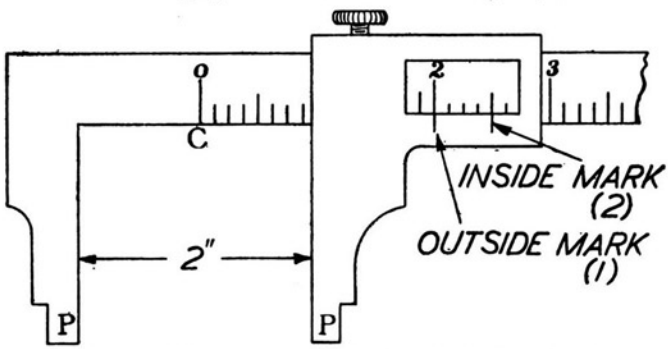

Fig. 14.— A slide gauge with double index for inside and outside measurement

upon the bar will commence from a point in line with the measuring part of the fixed jaw ; but in fig. 14 the bar will be marked at a point (C) which is at such a distance from the

measuring part of the fixed jaw that it will be opposite the outside mark 1 upon the movable jaw when the caliper is completely closed ; the inside mark 2 will then be opposite a line which gives the width of the projections P, P. If the smallest hole into which they could enter is $\frac{1}{4}$ in. diameter, then the mark 2 will be opposite the $\frac{1}{4}$ in. line on the bar (see fig. 15).

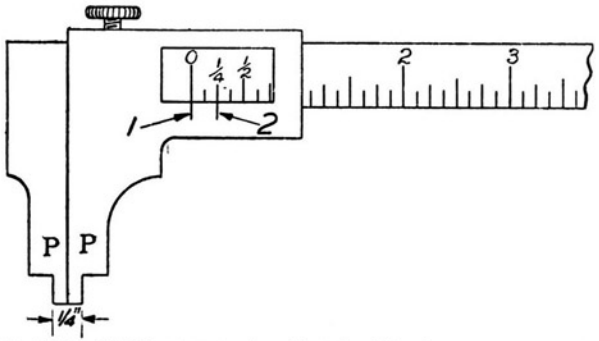

Fig. 15.—Slide gauge having inside jaws measuring $\frac{1}{4}$ in. in the closed position

The first thing to do with an unfamiliar caliper is to close the jaws completely, and then examine the movable one to find out the mark or edge which is opposite the zero line on the bar Note that the line on the bar, at which this mark points, indicates the extent to which the jaws are open,

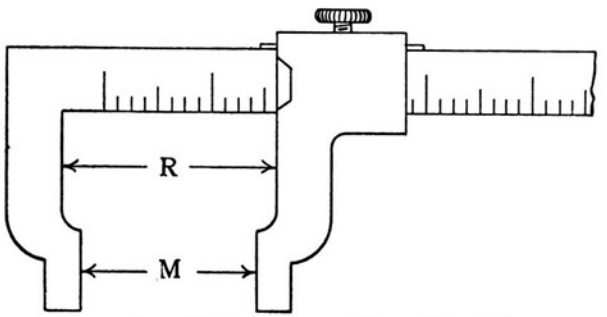

Fig. 16.—Slide gauge with relieved jaws

and therefore the size of the object between them. Or if the calipers are to measure inside dimensions also, as in figs. 14

and 15, the second mark should be noted as the one to be used when inside measurements are made. To become familiar with the caliper, set the marks to various dimensions, and then test the jaws by applying a rule to them. It should be noticed that caliper jaws are sometimes relieved near the bar, so as to confine the measuring edge to the outer part (see fig. 16). When this is the case, measurements must be made with the parts of the jaws marked M, and not between the

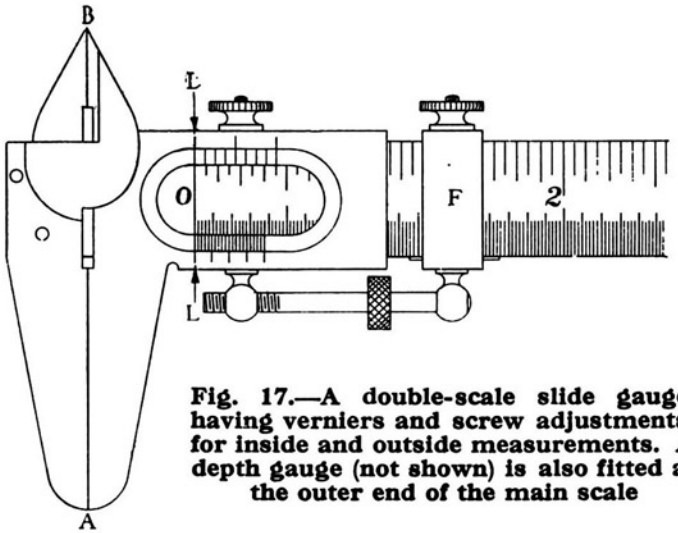

Fig. 17.—A double-scale slide gauge, having verniers and screw adjustments, for inside and outside measurements. A depth gauge (not shown) is also fitted at the outer end of the main scale

parts marked R, as the latter are not intended to be used, and would give a false indication on the bar.

The "Columbus" Gauge

A popular form of slide gauge is that known as the "Columbus" (fig. 17). When this gauge is completely closed, the zero line L L on the bar is opposite the end line of each of the two small scales engraved upon the movable jaw; these particular lines are, therefore, the marks to be used when reading the measurements of the gauge, both for inside and outside; because in this caliper the jaws provided for the two kinds of measurement are in line. If the jaws are opened to the extent of 1 in., it will be found that the lines L L on

the movable jaw are exactly opposite the 1 in. mark on the bar ; and if a rule is applied to the extensions A and B of the jaws, the distance will be 1 in. in each case. The true reading is thus not the part of the scale on the bar at which the line A B of the jaws is situated, but that part of the scale to which the lines L L are pointing.

To facilitate the adjustment of the movable jaw, a clamp F is provided in the more expensive calipers ; it has a screw attached to it by means of which the movable jaw can be

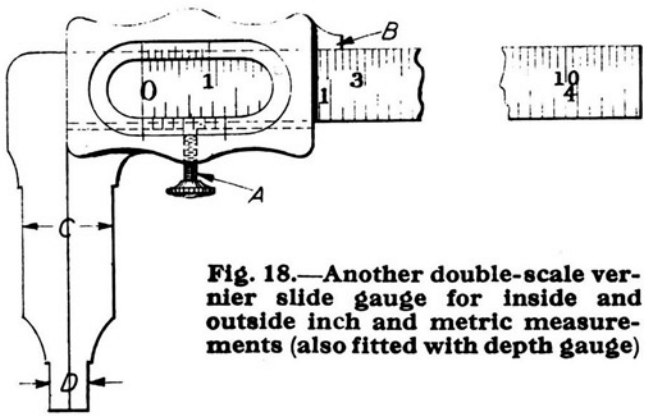

Fig. 18.—Another double-scale vernier slide gauge for inside and outside inch and metric measurements (also fitted with depth gauge)

slowly advanced or receded, and its movement easily observed and controlled. The depth gauge fitted to the Columbus caliper is also read to the same marks (L L) upon the movable jaw. When these marks are opposite the 2 in. line on the bar, the depth gauge will (if measured by means of a rule) be found to protrude exactly 2 in. from the end of the bar.

Fig. 18 shows a simpler form of double-scale slide gauge, which has no screw adjustment, but is locked in position by the setscrew A. With this, B is the depth gauge reading on a scale on the opposite side, while C and D are inside measuring surfaces, the breadth of which has to be measured and allowed for. This gauge and the one shown in fig. 17 are fitted with verniers (see Chapter III).

CHAPTER III

VERNIER SCALES AND HOW TO READ THEM

THE Vernier scale, which takes its name from the inventor, is, as already noted, fitted to several kinds of instruments, and particularly to slide gauges. Many people find it difficult to understand how to read a vernier scale, and it is therefore considered appropriate to devote a chapter to its explanation.

Use of the Vernier Scale

First of all, it is desirable to have a clear understanding as to why a vernier scale is used, and this question may be dismissed at once by saying that it is a means of registering increments of measurement which are too fine to be engraved on a plain scale. If one examines an engineer's ordinary steel rule, it will be found that the smallest division engraved upon it is 1-64th in., and most mechanics would say that this is because it is the finest division which can conveniently be read with the naked eye. While this is to some extent true, it is still more correct to say that it is because any finer engraving on the scale would not be suited to standing up to the wear and tear which a steel rule normally encounters, while remaining legible and definite. Scales can be engraved to an almost incredible fineness, and in the case of some laboratory instruments, it is found necessary to fit a microscope over the scale in order to read the finer divisions accurately. Such a method would clearly be unsuited for use in connection with workshop instruments, and it is usual to incise the lines fairly deeply on the scales of such instruments in order to eliminate the possibility of their being

erased or obliterated. The lines are cut with a vee-pointed cutting tool, and thus have a measurable breadth as well as depth ; this fact limits the possible number of lines which can be engraved in a given length, so as to leave clear spaces between them.

In instruments having a sliding scale with an engraved index mark, moving over the divided measuring scale, the measurements are read by the position of the index relative to the divisions, and it will be found that very small discrepancies from exact coincidence of the index mark with any particular division are easily detected by a break in the smooth continuity of the line formed by their junction. If, then, it were possible to find a means of measuring the amount by which the lines fail exactly to coincide, much finer measurements than those actually engraved on the scale could be made.

This is done in the vernier scale by comparing the divisions on the main scale with very slightly different divisions on another scale on the sliding member. Obviously, only one of the divisions on the sliding scale can correspond with one of the divisions on the main scale, and thus subdivision of the dimensions of the latter may be made, to a high degree of accuracy. This may be described as a " differential " method of measurement, and provided that the scales on both fixed and moving members are divided to a high degree of initial accuracy, it is highly effective in practice.

Application of Differential Method

To explain, in a simple way, how this principle may be applied, take first the case of a slide gauge, fig. 19, in which the smallest division on the main scale is a quarter of an inch. The sliding member, which has a zero mark at C in the usual way, is equipped with a vernier scale extending from C to D, and divided into four parts, the total distance occupied by this scale being equal to three of the divisions of the main scale. The *difference* between the length of four divisions

on the vernier, and four divisions on the main scale, is thus $\frac{1}{4}$ in., which is equivalent to saying that the difference between any one division on the vernier and one on the main scale is 1-16th in.

To read the scale, the dimension on the main scale which is nearest to the left hand side of the zero mark C is first

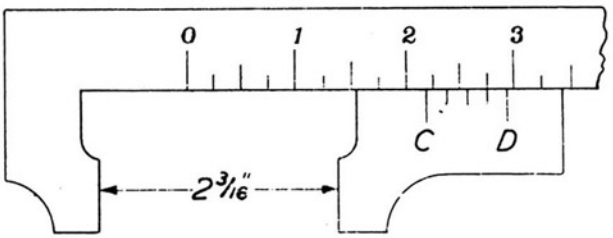

Fig. 19.—Example of a vernier scale to measure 1-16ths on a scale marked in quarter-inches

noted ; in the example shown in fig. 19, this is 2 in. Increments of $\frac{1}{4}$ in. are all read directly from the mark C, but the finer subdivisions of 1-16th in. are read by noting which division of the vernier scale exactly coincides with a division of the main scale. In this example, the third mark from C fulfils this condition, and therefore three vernier increments, or 3-16ths in., are added to the directly read measurement.

In practice a vernier would never be used to measure so coarse an amount as 1-16th in., which can be measured easily enough from a plain scale ; the example is given merely to show the principle, which holds good for any kind of vernier scale instrument.

To find the degree of subdivision which may be obtained with an unknown vernier scale, it is only necessary to take the number of divisions per inch (or centimetre, as the case may be) and multiply them by the number of divisions in the vernier scale. Thus, if the main scale is divided in increments of 1-40th in., and the vernier has ten divisions, it will measure to a limit of 1-400th in.

The Columbus gauge has two vernier scales and two sets of

bar divisions ; one set—that nearest the adjustment screw—enables measurements to be made to one-thousandth part of an inch, and the other to the 1-128th part of an inch—that is, to half of 1-64th in.

The 1000th in. Vernier

The 1-1000th in. vernier is constructed and used as follows. The bar is marked with divisions of 50 to the inch as its smallest divisions. Now, it is easy to set the mark L (figs. 17 and 20) on the jaw to these lines, and so make measurements to the 1-50th part of an inch, or even to guess fairly near to half a division, which would be the 1-100th part of an inch. But it would be hopeless to try to set it to the 1-20th part of a division, which would be necessary to measure the 1-1000th part of an inch ; so the vernier scale is provided to enable this to be done.

A distance (L M) is taken, equal to nineteen of the smallest

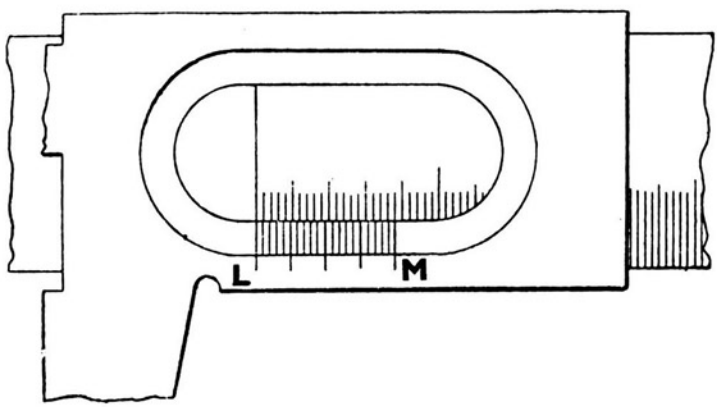

Fig. 20.—A vernier scale for reading to 1-1000ths of an inch

of the bar divisions, and the distance is divided into twenty equal parts. Each of these parts is thus smaller than a bar division of 1-50th in. by 1-20th of such a division ; but the 1-20th part of 1-50th in. is the 1-1000th part of an inch. So

it follows that each vernier scale division is the thousandth part of an inch smaller than a bar division ; and that if you start at L, and count the vernier scale to M, you will count

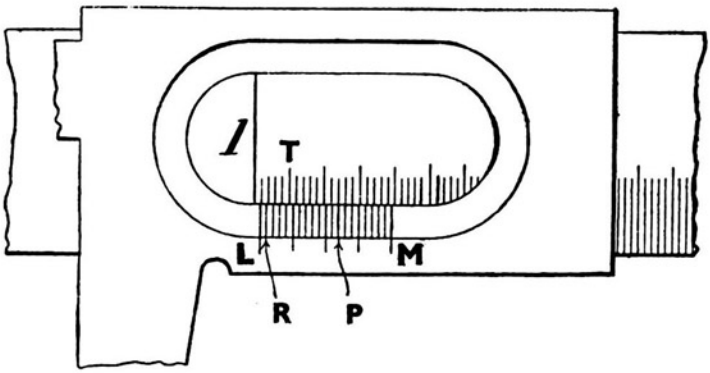

Fig. 21.—A 1-1000ths vernier scale, set to read 1.012 in., or 1 in. plus 12-1000ths

1-1000th of an inch short for every division, until you come to M, when you will have completed twenty, which make up the one bar division by which the vernier scale is shorter than twenty bar divisions.

To use the vernier scale, close the jaws until they touch the object to be measured ; then note the division that is nearest to the left hand of the mark L ; this gives the unit figure—say, 1 in., as fig. 21. Then note the vernier division, which happens to come exactly opposite to a bar division, and begin to count towards L ; when you reach L, the number of vernier divisions which you have counted indicates the number of 1-1000ths in. by which the object between the jaws exceeds 1 in. in size. In fig. 21 the vernier division P is the one to begin counting from as the zero mark. As there are twelve of these divisions between P and L, the measurement is therefore 1 in. + 12-1000ths in. or 1.012 in.

If the mark L has been near one of the larger subdivisions on the bar—say T (fig. 21), the first after the 1 in. mark—then you would, of course, begin to add the 1-1000th measure-

ments on to this, so that the measurement would have been 1 in. + 1-10th in. + 12-1000ths ; or 1.112 in. You should always proceed in this way, determining first the unit, and then the fraction to be added, each division on this particular vernier scale counting as 1-1000th in., and the counting to commence from the vernier mark, which happens to be opposite a mark on the bar, always in the direction from M to L. It would come to the same result if you commenced counting at the vernier mark L and continued until you reached a mark opposite a bar division ; this would only be another way of counting. You can use the method that seems the more convenient.

Supposing that the mark L was in excess of the 1 in. mark on the bar by a very small amount, and that the mark R was the vernier scale mark that was exactly opposite to a mark on the bar, it would then show that the size between the jaws was 1-1000th in. more than 1 in., because you would count only one scale division on the vernier. As by the principle of the vernier you know that the difference between a division on the bar and a division on the scale is 1-1000th in., a movement of the jaw of exactly this amount has been required to bring mark R opposite a bar division.

When measuring sizes from 0 to 1 in., of course, there will be no unit figure, as only fractions will be involved ; but the method remains the same. You take the largest bar division to the left of L, and then add to it the amount in excess—say, 1-10th in. + 1-50th + 3-1000ths would give .123 in. This would mean that the mark L was beyond the first large subdivision on the bar by one of the smallest divisions, plus an amount which is calculated by counting vernier divisions.

The second vernier scale on the Columbus gauge is made and used in a precisely similar manner. But in this case the smallest divisions on the bar are 1-16th in. ; so that measurements are not made to decimal fractions, but to the usual subdivisions of 1-16th in. ; that is, to 1-64th, and the half of this, viz., 1-128th in., or half sixty-fourths,

as one would usually call it when reading from an ordinary rule.

Uses of Columbus Gauge

An examination of the Columbus gauge will show that this vernier scale has a length equal to seven of the smallest bar divisions ; that is, 7-16th in., and is itself divided into eight parts. Each vernier division is therefore 7-8th of one of the smallest of the bar divisions ; as these are 1-16th in., it follows that the difference between the two is half 1-64th in.; that is, 1-128th in., as there are four 1-64th in. in one 1-16th in. division. This vernier enables comparisons to be made to small differences in 1-16th in. measure, and is thus useful for the less exact class of workshop measurements ; whilst the other vernier can be used for measurements to an accuracy of 1-1000th in., though it is quite easy to reckon 1-100th in., as the vernier will count ten divisions exactly whenever the amount is 1-100th in. Inside measurements and depths are shown by the same lines that indicate the size of objects between the jaws.

The verniers in fig. 18 are divided to determine 1-128th in. on the lower scale, just as the upper one does in fig. 17, whereas the upper scale is metric, in which a vernier scale of 9 millimetres is divided into ten parts ; hence the difference here is 1-10th of a millimetre.

Some discretion is required occasionally, as no one of the vernier divisions may appear to be exactly opposite a bar division. When this occurs, you should select the one which seems to be the nearest to a bar division as the zero to begin counting ; and remember that the starting vernier mark is reckoned as 0, and not 1. It is necessary to use a magnifying glass to read small vernier scales properly, such as those on the Columbus gauge.

As well as its use in determining the size of a finished object, the vernier scale serves as an accurate means of gauging pieces made to given larger or smaller dimensions

than another piece. For instance, suppose a spindle is a tight fit in a hole, and you desire to reduce its diameter by a very small amount to make it an easy fit, you would set the jaws to 1-1000th in. smaller than the diameter of the spindle, and then turn it down until it fits the smaller opening of the

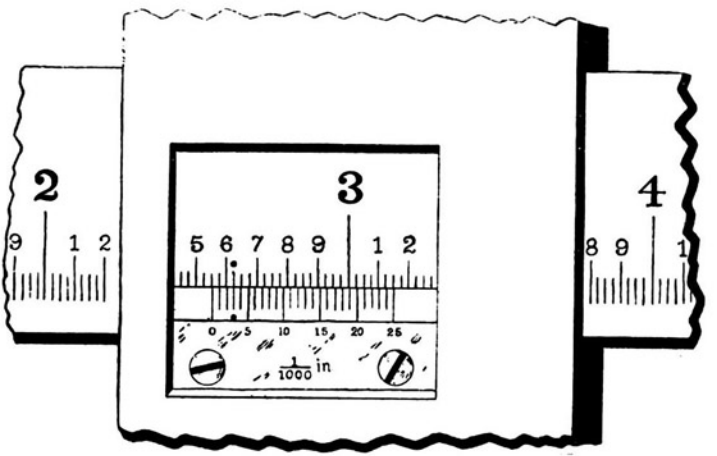

Fig. 22.—The vernier scale of a vernier height gauge. Setting (indicated by dots on main and vernier scales), 2.553 in.

jaws. First set the caliper to the exact size of the spindle, and then examine the vernier to find one of its lines, which was exactly opposite to a line on the bar ; the movable jaw is then closed, until the adjacent line to the left-hand is exactly opposite the next line on the bar. The opening between the jaws will now be smaller than before by an amount equal to the difference between the vernier and bar scale divisions. In the case of the 1-50th in. bar scale on the Columbus gauge this difference would be 1-1000th in. ; but if the 1-16th in. bar scale and vernier had been used, the difference would be 1-128th in., that is, half 1-64th in. By moving the jaw to the right, the distance to be measured would be made greater by the same amounts. It is also as easy to measure to greater amounts of difference by

counting more than one division to right or left. For instance, two divisions would equal 1-64th in., four divisions equal 1-32nd in., and so on; the adjustment being made by moving the jaw until the last division reckoned to right or left has been moved to a position opposite the next bar division.

It is most important that every engineering student and apprentice should become thoroughly conversant with the

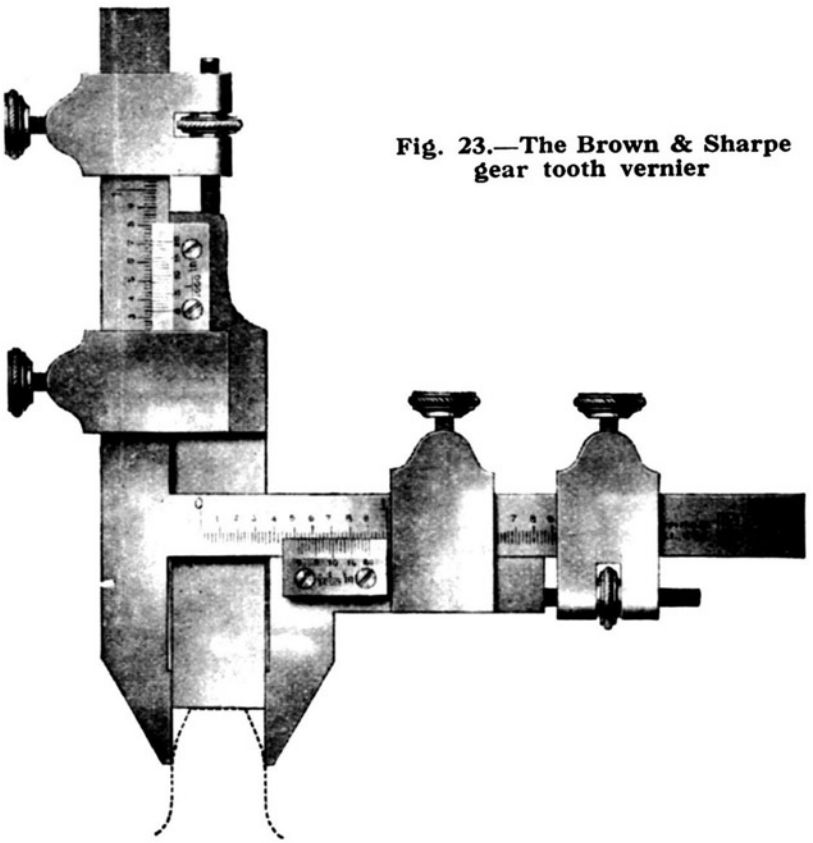

Fig. 23.—The Brown & Sharpe gear tooth vernier

use of vernier scales, as they are extensively used on many different instruments in the tool room, inspection room and laboratory of most modern factories.

The scope of this book does not allow of making more than a brief reference to instruments using vernier scales, other than those specified in the title. Mention has already been made of the use of the vernier scale in protractors, and this principle is further extended to the scales of sextants, theodolites, precision levels, and various forms of dividing apparatus. Depth gauges are also commonly equipped with vernier scales, and another instrument of great value for accurate marking out is the vernier height gauge, which is found in nearly all tool rooms at the present day. It consists of a vertical graduated scale, attached to a solid base, so as to stand truly perpendicular on the marking-off table or machine tool bed, and having a sliding member differing very little to that of a high-class slide gauge, including the vernier scale and means of fine adjustment. The sliding member may be used as a reference gauge, to which a scribing block or other gauge may be set ; or work may be marked directly from the height gauge by means of a marking point clamped directly to the sliding member. Fig. 22 shows the vernier scale of a height gauge, and it will be seen that it does not differ in any essential respect from that of the slide gauges described in this and the preceding chapter.

There are several types of special vernier slide gauges employed in engineering practice for the measurement of precision components which present great difficulty in applying ordinary measuring devices. An example of such a gauge is shown in fig. 23, which illustrates the Brown & Sharpe gear tooth vernier. This instrument is employed for the purpose of accurately measuring the thickness at the pitch line (termed the chordal thickness) of the teeth of gear wheels. To take this measurement correctly, it is most important that the tips of the gauge jaws should be applied at the correct depth of the tooth, as the thickness of the latter varies, above and below the pitch line. The tongue which slides vertically between the main jaws is used for

this purpose, being set to the required depth, as found by reference to a table of gearcutting data, or by calculation; allowance may also be made for variation or error in the size of the blank. Either English measurements (20 to 2 or 10 to 1 diametral pitch) or metric measurements ($1\frac{1}{4}$ mm. to 12 mm. or $2\frac{1}{2}$ mm. to 25 mm. Module) may be covered by instruments of the appropriate calibration range.

CHAPTER IV

MICROMETER SLIDE GAUGES

MICROMETER calipers, like the vernier calipers, are used to measure very small fractions, such as the 1-1000th in. Instead of a scale, however, the measurement is made by means of a screw of accurate pitch.

Suppose a screw is cut with a pitch of 1-10th of an inch—that is, the distance from the top of one turn of the screw to the next is 1-20th in.—there would then be ten complete turns in 1 in. (see fig. 24). If this screw were made to fit nicely into a nut, the following actions could be effected :—

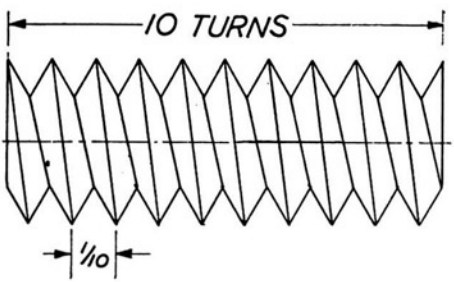

Fig. 24.—The relation of the pitch to the number of threads in a screw

(1) If the nut were fixed so that it could neither turn round nor move and the screw were rotated, its end would advance; the point, being flush with the face N of the nut (fig. 25) at the commencement, would move forward to P, a distance of exactly 1 in., when the screw had been rotated by exactly

ten revolutions ; with five revolutions it would move ½ in. ; with one revolution 1-10th in. ; and so on. (2) If the screw were fixed and the nut free to move, it would travel along the

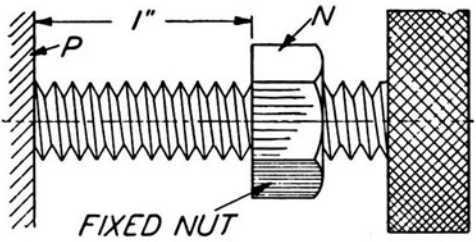

Fig. 25.—A fixed nut on a revolving screw

screw a distance of 1 in. (fig. 26), when rotated through ten revolutions, or 1-10th in. for one revolution, and so on. (3) If the nut were free only to rotate but not to move sideways, and the screw were free to move but not to rotate, ten revolutions of the nut would cause the end of the screw to move exactly 1 in. from N to P (fig. 27) ; one revolution of the nut would cause it to move 1-10th in., and so on. It

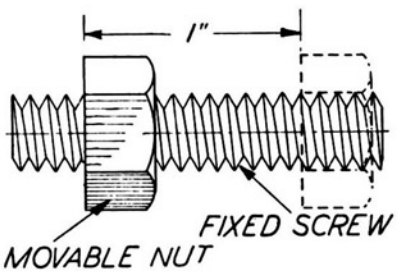

Fig. 26.—A revolving and movable nut on a fixed screw

will be seen from this that we have here a means of measuring the movement of a surface attached to a screw or a nut, provided we know how many turns the screw makes round its axis in a given distance. Also, if the end of the screw

formed the movable jaw of a caliper, we could measure the amount of opening of the jaws by counting the number of revolutions of the screw or nut that had taken place to open the jaws to any amount.

To measure very small fractions we can count portions of a revolution. For instance, if only half a revolution had been given to the screw or nut, the amount of movement would be half 1-10th in., that is, 1-20th in.; if only one-tenth of a revolution had been given, the movement would be only the tenth part of 1-10th in., that is, the 1-100th part of an inch; and so on. To ensure that the correct amount of movement shall take place it is necessary to provide some kind of indicator to show when the screw or nut has been turned through a complete revolution or fraction of a revolution; it is also essential that the screw be made of accurate pitch, or else the measurement will not be correct. Though it is possible to compensate for inaccuracy, the screw is usually cut sufficiently well to render such precaution unnecessary.

The Screw Head

The method adopted, to show the amount of rotation which has been given to the screw, is to provide it with a plain circular head marked with a convenient number of equal divisions—ten, for instance—the lines dividing the circumference of the head exactly into ten parts (see fig. 28). A complete or fraction of a revolution can then be accurately determined by adjusting the lines on the screw head so that they come exactly opposite to a fixed line or mark, such as the straight-edge A (fig. 28). The number of revolutions is determined by observing the position on the scale A of the edge B of the divided head. A is marked with divisions corresponding to the pitch of the screw, and one complete revolution of B will cause the screw to advance one division along A. To ascertain the size of a shaft, for instance, you would place it between the end of the screw C and the face D; the screw is then rotated until the shaft is just touched by

C and D. If it was exactly 1 in. in diameter, for example, the edge B would be opposite to the 1 in. mark on A, and the 0 mark on B would be in line with the edge of A. If, however, the diameter of the shaft were slightly larger than 1 in., the 0 mark on B would not be in line with A, but one of the other marks would be there, because B would have made a fraction of a revolution more than the exact number of revolutions necessary to move the end of the screw a distance of 1 in., and the number on B, which was in line with A, would indicate the value of this fraction. If the pitch of the screw was 1-10th in. and B was marked with ten divisions,

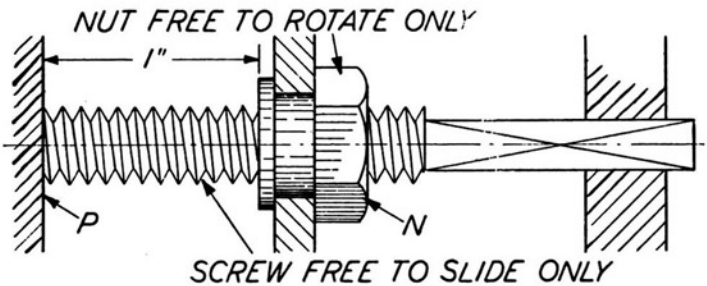

Fig. 27.—A revolving nut on a sliding screw

the shaft would be 1 in. + 1-100th in. diameter if mark 1 was in line with A, or + 5-100ths in. if mark 5 was in line with A, and so on.

By subdividing the ten divisions on B, the measurement can be made to a greater degree of accuracy. A subdivision to five parts would mean that the end of the screw would advance 1-500th part of an inch for each small division moved past the edge of A, because B would now be divided into fifty parts, so that the 1-50th part of a revolution is indicated. The pitch of the screw being 1-10th in. it is advanced 1-50th of its pitch—that is, 1-50th of 1-10th in. = 1-500th in.—for each small division moved past the edge A. Such an instrument is called a "micrometer caliper," and is an

application of the principle illustrated in fig. 25. The commercial form of this kind of caliper is an improvement upon the construction as shown in fig. 28, the screw being protected as much as possible and adjustments provided to compensate for wear and to lock the screw in position ; but the principle is precisely the same as described.

Micrometer Slide Calipers

The micrometer principle is sometimes applied to slide calipers for making accurate measurements of small amounts instead of a vernier scale, removing the uncertainty of deciding at which line to begin counting, as with the vernier.

A good form of micrometer slide caliper is shown in fig. 29. In appearance it is very similar to the caliper described in fig. 17, and the general remarks regarding the marking of the scale, method of determining the division to be taken when reading a measurement, and construction, are applicable to these calipers. The distinguishing feature is the use of a micrometer screw and nut instead of a vernier scale to indicate minute fractions of the divisions marked on the bar ; it is an application of the arrangement explained in fig. 27. The movable jaw B is provided with a screw S fixed so that it cannot rotate ; upon this screw is threaded a nut M which can rotate upon the screw but cannot move along it, being held between the arms of the sliding clamp F. When this clamp is fixed to the bar by means of the setscrew N, the jaw B will be moved along the bar if the nut M is rotated, the amount of movement per revolution or part of one depending upon the pitch of the screw.

Suppose now that the bar is marked into divisions of $\frac{1}{4}$ in. each as its smallest divisions, and that the screw has a pitch of $\frac{1}{4}$ in. also, it is evident that B will move that amount for one revolution of the nut M ; for half a revolution of M it will move half a quarter of an inch, that is, $\frac{1}{8}$ in. ; or for a quarter of a revolution of M the movement of B will be a quarter of a bar division, that is, 1-16th in. ; and so on. It will be seen

that, provided we can accurately determine small fractions of a revolution of M, we can easily measure to very small fractions of a bar division. This is where the benefit of the micrometer screw principle appears, because we have only to mark the surface of the nut M into divisions corresponding to the smallest fraction of a revolution which we desire to indicate, and to provide a fixed zero mark on one of the jaws of F, to enable any fraction of a revolution of M to be determined. Further, by making the diameter of M large enough, we can ensure that the divisions marked upon it are so large that they can be read without the aid of a magnifying-glass.

As very small fractions are more conveniently expressed as decimals of an inch, it is usual to arrange micrometer calipers to indicate to the 1-100th part of an inch. The actual size of the bar divisions would depend upon the pitch of the screw ;

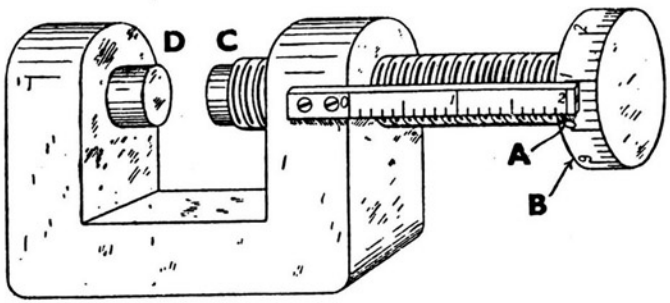

Fig. 28.—An elementary form of screw micrometer

a convenient division is the 1-40th part of an inch, the screw being of the same pitch. If the surface of the nut M is then marked into twenty-five divisions and it is turned through that part of a revolution, the jaw B will be moved an amount equal to one-twenty-fifth of a bar division, which is equal to 1-1000th in., because 1-40th × 1-25th = 1-1000th.

To use such a caliper, the object—say, a round piece of steel—to be measured is placed between the jaws A and B,

and they are closed until they just touch it ; the position of the indicating mark L on the movable jaws is then noted. If it is exactly opposite to a bar division, the size can be at once noted ; but if the mark is slightly to one or the other side of one of the marks on the bar, you must use the micrometer to determine the fraction of a division by which the measurement is short of or beyond the mark on the bar. For instance, suppose the bar to be exactly 1 in. in diameter, then the mark L will be exactly opposite the 1 in. mark on the bar ; but if L is slightly beyond the 1 in. mark, it would show that the bar was larger than 1 in. in diameter by some small fraction of an inch.

To determine this fraction, first clamp the jaw B by means of its setscrew D so that it cannot move, and remove the steel bar from between the jaws, leave N slack, then rotate the nut M until its 0 line is exactly opposite the mark P ; now screw up N so that the clamp F cannot move along the bar ; slacken D so that B is free to move. The nut M is now to be rotated until the mark L is exactly opposite the 1 in. mark on the bar ; the amount of rotation of M will indicate the distance which the jaws have had to be closed to bring L to the 1 in. mark, and, therefore, the exact size of the bar which is being measured. If the nut only required turning through an amount equal to one of its divisions, the jaw B would have moved only 1-1000th in. ; therefore, this would be the amount by which the diameter of the steel bar exceeded 1 in.—its size would therefore be 1.001 in. If the bar had been smaller than 1 in., the operations would have been precisely the same, except that the nut M would have been rotated in a direction to open the jaws until the mark L had reached the 1 in. line on the bar ; the reading would then show that the steel bar was .001 in. smaller than 1 in. in diameter.

You would proceed in exactly the same way if you wished to make one bar smaller or larger than another by a certain amount—say, 3-1000ths in. You would set the caliper so

that it measured the diameter of the bar which was not to be altered ; then tighten up D, slacken N, set M so that its 0 line was opposite to P ; tighten N, slacken D, and rotate the nut M by as many divisions as required by the alteration in size. In this case, three divisions one way or the other would move the jaw B by 3-1000ths in., which is the difference required ; then finally tighten up D, and turn the new bar until it fits exactly between the jaws. If the jaws were fitted with projections (H H) for measuring the diameters of holes, the same

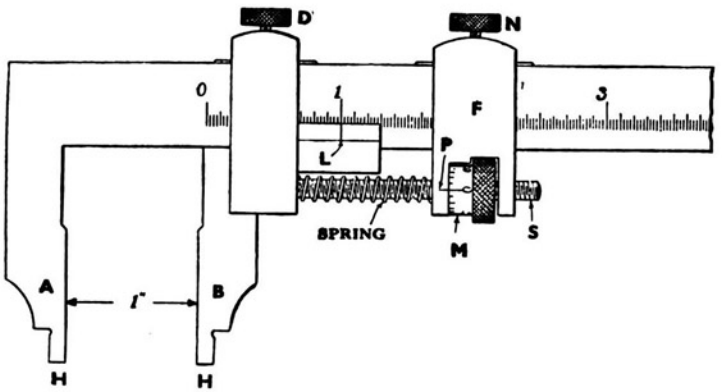

Fig. 29.—Starrett micrometer slide gauge for inside or outside measurement

operations would be used to measure holes of different sizes, to alter a hole by a given amount, or to measure the sizes of spindles, etc., which were required to fit into a hole with a certain degree of allowance.

Micrometer slide calipers are sometimes arranged with a movable screw (as in fig. 28) fitted to the sliding jaw, instead of the arrangement of nuts as fig. 29. With these instruments the mark L is first set exactly opposite to a line on the bar which corresponds nearest to the size of the object to be measured. The micrometer screw is then adjusted until the object to be measured is clipped between the jaws and the difference in size is read directly from the divisions

marked on the micrometer screwhead. These are called " Beam Micrometers."

The vernier caliper depends for its results largely upon the accurate marking of the scale ; the micrometer depends as well upon accuracy in the pitch of its screw. The backlash, or movement which is always present between a screw and nut, is counteracted in the caliper shown in fig. 29 by means of a spring which is coiled round the screw and, pressing outwards between the jaw B and clamp F, always keeps the nut M tightly against the thread of the screw. In micrometers such as shown in fig. 28, the nut in which the screw works is usually split, and clamped by means of a screw, or screws, in such a manner that the backlash is eliminated.

Micrometer and Vernier Combined

It will probably occur to you that by combining the principles of the micrometer and vernier, exceedingly small measurements could be made ; this, as a matter of fact, is sometimes done in calipers to measure to the 1-10,000th part of an inch. If, for example, a circular vernier scale was engraved on the extension of F, in place of the single mark P, the marked surfaces at P and M meeting one another, a movement of 1-10th of a division on M could be easily read by the aid of a magnifying glass : this would indicate a movement of the jaw B of 1-10,000th in. Such calipers are only used for exceedingly accurate work. The usual workshop micrometer or vernier caliper reads to the 1-1000th part of an inch (see Chapter VI).

It is necessary to take some precautions when using slide calipers and micrometers if reasonably reliable measurements are to be made. There may be some slight error in the divisions, or the opening between jaws may not exactly correspond to the indications of the mark which points to the divisions on the bar, as it is almost impossible to make such articles free from error. A new caliper should be examined, and if an inaccuracy in the reading is detected, the

amount should be noted, so that it may be allowed for when measurements are made. Close the jaws and note if the indicating edge or line is exactly opposite the zero mark on the bar; it may be slightly to one side or the other and if so all measurements should be made on the basis of this error. Be careful not to strain the caliper when closing the jaws; especially is this the case with micrometers and screw adjustments. The screw should only be moved with the slightest possible pressure, so that you can feel the contact between the measuring surfaces and the object to be measured.

When comparing two articles, unless they are clipped between the jaws with exactly the same amount of force, the measurement as indicated by the caliper will not be correct. To guard against this fault, some micrometer screws are provided with a ratchet in the milled head, by which the screw is rotated. This ratchet slips as soon as the jaws grip the object with a certain pressure, to ensure that all objects are subjected to the same force; and, consequently, any difference indicated by the caliper will be due to size. It is quite easy, for instance, when measuring the diameter of copper wire, to flatten it to some extent when clipped between the jaws of a micrometer caliper, and thus obtain a false measurement. With all patterns of bar calipers it is important to tighten up the setscrews, such as D and N (fig. 29), when the final measurement is made, except for temporary or approximate measurements, as the jaws may not be accurately square to the bar when the setscrews are loose (see end of Chapter VI).

Fine Adjustment

To make a fine adjustment of the movable jaw by means of the screw S (fig. 29), the clamp F should be fixed by means of its setscrew N, whilst the setscrew D is slackened so as to allow the jaw B to move along the bar. Always see that one of the screws—D or N—is slack before using the adjustment screw, for if the jaw and clamp should happen to be fixed

tightly to the bar, there is risk of straining the screw and nut. These remarks also apply to the caliper shown in fig. 17, as, though the screw here is not a micrometer screw, and therefore not used as a means of making measurements, yet it is better to avoid straining it.

Good bar calipers are usually fitted with flat springs between the points of the clamp screws and the bar, or the clamps and jaw are made to fit spring-tight upon the bar, so that it is possible to make them slide with a certain amount of friction. The object of this is to prevent the jaw from shaking about, and to preserve accuracy of measurement; you should therefore adjust the clamping screws so that a slight effort is required to move the jaw and clamp when making a measurement. An experimental trial will show just the amount of stiffness which gives good results. Remember that calipers which are to be used for measurements of 1-1000th in. should be carefully treated; if allowed to fall or be strained, they will not be reliable. The screws of micrometers should be kept in good preservation, as upon their condition accuracy of measurement depends.

CHAPTER V

DETAILS OF MICROMETER CONSTRUCTION

FIG. 30 is a part section of a usual form of micrometer, and one which in the hands of a skilful workman will read to as fine a dimension as 1-10,000th of an inch. The parts are as follows : A is the frame in one piece with the sleeve B, which is internally threaded in a portion of its length with forty threads to the inch. In this works the screw spindle C, which is in one piece with the thimble D. This latter works

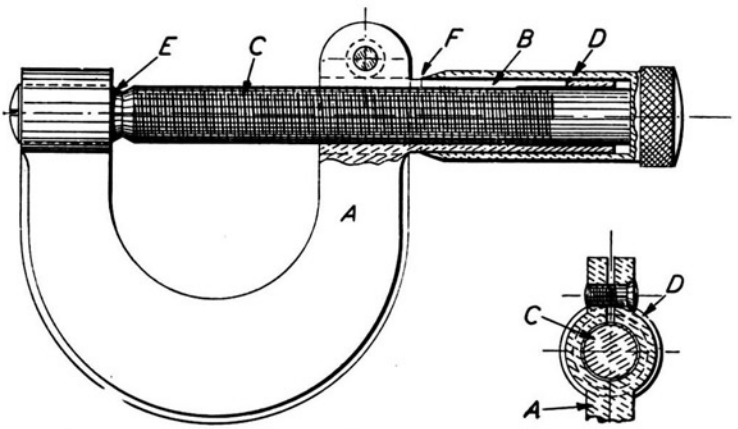

Fig. 30.—An early English type of screw micrometer

upon the outside of the sleeve, and has a milled portion at the end of the outside for convenience in operating the screw. The sleeve is split from the inner end for a portion of its length, rather longer than the internal thread, and is carried upward over the end of the frame in the form of two lugs. One of these is screwed, a countersunk screw being

introduced to draw the lugs together, and incidentally to close together the sleeve so as to either take up wear on the screw or grip it rigidly ; E is the adjustable anvil, which is tightly screwed into the outer arm of the frame. The inner surface of this constitutes the zero mark on the micrometer. When the end of the screw butts on to this, the recording edge F of the thimble stands level with the zero of the scale on the sleeve.

Sleeve Scale

This latter scale is divided along a line running parallel with the axis of the screw, and is engraved upon the outside of the sleeve. On a 1 in. micrometer this scale consists of 1 in. divided up primarily into ten divisions, each 10th being divided into a further four. As the screw has forty threads to the inch, one of these small divisions corresponds to a revolution, and being 1-40th in. is therefore equivalent to 25-1000ths. To reduce the measuring capacity, it is therefore necessary to divide the circumference of the thimble into 25 divisions. This is done upon the edge F, the scale being marked out into five primary divisions, marked 5, 10, 15, and so on ; 0 and 25 being engraved against the same mark. If, therefore, the thimble be unscrewed from its zero mark through one of these 25 divisions, the point of the screw has been withdrawn from the face of the anvil through a space equal to 1-25th of 1-40th, which is 1-1000th of an inch. A certain amount of familiarity is necessary to read a micrometer in thousands of an inch readily, but it should always be remembered that the primary divisions on the sleeve scale equal 0.1, 0.2, 0.3 (and so on) of an inch, always also remembering to add 25-1000ths for each small division, and in addition to add to this amount the number of thousandths to their zero recorded upon the circular scale on the edge F of the thimble. In metrical micrometers the screw has two threads per millimetre, and the thimble fifty divisions, giving 1-100th mm. per division = 1-2540th in.

Fig. 31 is a section of a micrometer made by Messrs. Brown & Sharpe, of Providence, Rhode Island, U.S.A. It will be noted here that the arm of the frame carrying the anvil is reduced considerably, almost to the diameter of the anvil itself, and that there is no bevel upon the edges of the measuring surface ; consequently the measurements can be made close up against a shoulder, which is impossible in the older form. In addition to this, the screwed portion of the spindle does not project beyond the inner arm of the frame, because the internal threaded portion of the sleeve is on the outer end, and the whole of the screwed portion of the spindle is enclosed in the sleeve. As the spindle has now a smooth turned surface, a very apt device is added in the form of a split bushing, shown at A, which has a tapered external thread articulating with a similarly screwed milled nut. The action of this is that when it is screwed up tightly, the arms of the split bushing grip the spindle, with more or less frictional resistance, so as either to lock the micrometer or render it more suitable for use by a heavy-handed person.

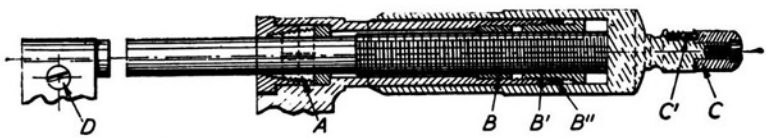

Fig. 31.—Section of a Brown & Sharpe micrometer with collet locking device

The internal screwed portion of the sleeve is made in two separate parts, shown at B and B′, portion B being fixed tightly. Portion B′ is screwed into the sleeve, and fitted with a locknut B″, so that any backlash which makes itself apparent in the nut, due to wear, can be rectified by moving B′ against the fixed nut B, locking it in its new position by means of the locknut B″. Any degree of tension can be put upon the screw permanently by this means without any reference to retardation of action brought about by the use

of the locking device shown at A. The small milled projection C is known as the ratchet stop, and is applied to micrometers for the purpose of ensuring that the same degree of pressure is applied to an article being measured by one person as by another. A ratchet pawl C′ allows of the free movement of the thimble and screw until such pressure as is sufficient to record the exact size of the article between the points is reached, when it gives way and allows the milled end C to slip round with the characteristic clicking noise peculiar to a ratchet. The action of this is positive on the unscrewing direction, so that by means of the small diameter of the finger piece, the micrometer can be unscrewed at a much greater rate than if it were to be operated by the larger diameter of the thimble itself. The method of graduating these tools is exactly the same as the one described above. The function of the screw shown on the frame at D is to allow

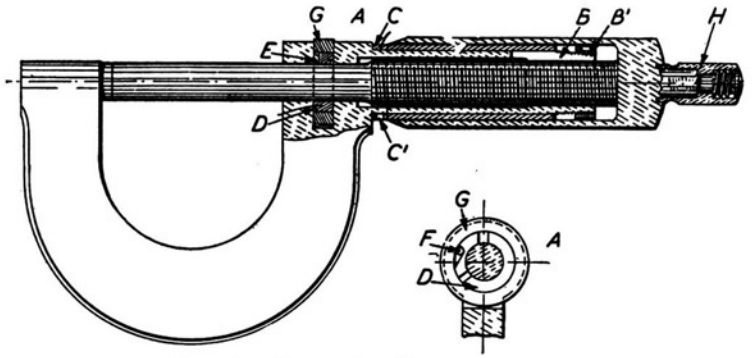

Fig. 32.—Sections of a Starrett micrometer

of the adjustment of the anvil to compensate for wear between it and the end of the spindle.

Quick Action Locking Device

Figs. 32 and 33 illustrate micrometers as made by the L. S. Starrett Company. The principal features here are a quick-action locking attachment A, fig. 32, shown in cross section in the same figure—with an improved method of taking up

wear B, and a device C for setting the index on the sleeve to the zero on the thimble. Fig. 33 constitutes quite the latest departure in this class of tool—a quick-action adjustment. Referring to A, fig. 32, a cross slot is cut in that portion of the frame continuous with the sleeve, and a steel cut ring D

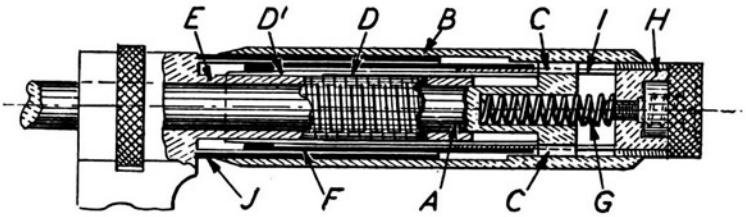

Fig. 33.—Starrett's quick adjustment micrometer head

is introduced surrounding and nicely fitting the spindle. This ring is prevented from turning by conflicting with a key-piece E on the frame, which articulates with a slot in the side of it. There is also a silent roller ratchet F, which allows the outer milled ring G to revolve in one direction; but immediately this is turned slightly in the opposite direction the roller takes up and closes the inner ring D on to the spindle, locking it very rigidly. The feature in this is the quick-locking action. The device C, which consists of an outer shell of the sleeve, and on which is engraved the scale, is free to revolve on the inner sleeve. Being a tight fit, it can only be conveniently operated by means of a small ring spanner (provided) working in the opening C'. Should the anvil or spindle show signs of wear and the zero on the thimble advance beyond the index on this loose sleeve C, a slight turn forward with the spanner will align zero and index. The inner sleeve is threaded at the point B, and is further split (chuck fashion) in three places, so that any wear in the sleeve can be obtained by screwing the nut B' up the tapered jaws, also by means of the ring spanner. The ratchet stop H, having two reverse ratchet wheels which fit together and are kept so by a spiral spring until

the resistance becomes too great, forms a very good wearing device and a very positive one in back action.

Principle of the Quick Adjustment

In fig. 33, the principle of the quick adjustment is well worked out in the following manner. The spindle A, turned smooth and parallel throughout, is attached to the thimble B by means of a boss and four spokes or wings, two of which are shown at C, C. In one with the boss, and outside the spindle, is a thin split barrel D, carrying the internal thread at its further end D′. This works upon the male thread cut upon an inner sleeeve E, which is one with the frame of the micrometer, and is bored to fit the spindle. The thread is of buttress form with the vertical face of the male thread on E facing in the direction of the anvil to facilitate the action of gearing together. Normally, the sections of D would spring out, so that its threads would clear the threads on E. The end of a sheathing cylinder, however, shown in solid section at F, clips the points of D on their outside tapered surfaces, and the forcing action of the spring G (by means of the ratchet box H and slotted cylinder I) closes the female thread and holds it firmly to its work during the action of finely adjusting the instrument. It will be noticed that the cylinders I and D are joined. But should it be necessary to open out or close the

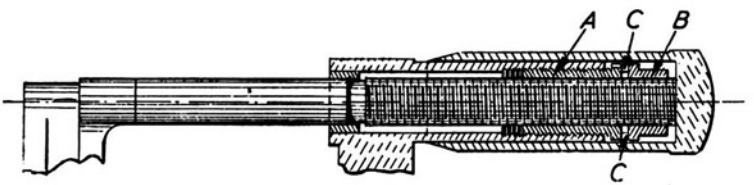

Fig. 34.—Section of a Slocombe micrometer

spindle some considerable distance, all that is necessary is to compress the ratchet box into the thimble by pressing the thumb into its hollowed-out end (the thimble being held meanwhile between the first and second fingers) against the spring G. F, having passed the points of the spring barrel

D, will then release the threads and allow the spindle to be moved to any position or withdrawn entirely from the frame. The cylinder F is made separate from the slotted cylinder I, as the length of the slots in the latter determines the limit of the action of the spring ; and the tension of F, which can be screwed on and off I, determines the tension between the male

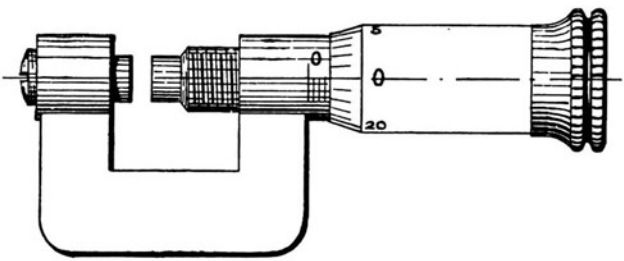

Fig. 35.—Small German-silver micrometer

and female thread. This tool is fitted with the outer adjusting sleeve J, and in fit, action, and accuracy, is one of the finest pieces of work to be seen.

Taking up Wear

Fig. 34 shows the method of taking up wear in the Slocombe micrometer, which is of American manufacture. This micrometer is not fitted with any locking device, and has only recently been made with a ratchet stop. The principal feature is an ingenious device for taking up wear, which answers the double purpose of compensating for backlash and also for wear on the anvil and spindle surfaces. The internally threaded nut is made in two pieces, A and B. The former, which is the main nut, is externally screwed, with 32 threads to the inch, tightly into an internal thread of the sleeve. The second nut B is held in action with A, by means of a set of 56 V-shaped teeth on the annular surface of either nut shown at C. These teeth lock together. If, therefore, any backlash becomes apparent in the fitting of the main screw, all that is necessary is to withdraw the

spindle and advance the nut B one or more of these V-shaped notches, when the wear will be compensated for upon the principle of the ordinary locking nut. Normally, a slight tension is put upon the nut B by means of a light spiral spring inserted in the space C′. To compensate for wear on the anvil and spindle, the action of the differential screw brought about by screwing A, by means of its 32 threads to the inch, into the sleeve, as against the 40 threads on the main screw, will, in the case of such wear, bring the zero on the thimble back to its original mark. The worn surfaces are thus closed together; and by unscrewing A the opposite effect would be produced. These micrometers are made with a specially stamped and embossed frame, and, considering that they are regarded as cheap instruments, are wonderfully good value.

Cheap micrometers can be bought for a few shillings. They are usually of Continental make, and great care is necessary in the choice of such as these. The two forms

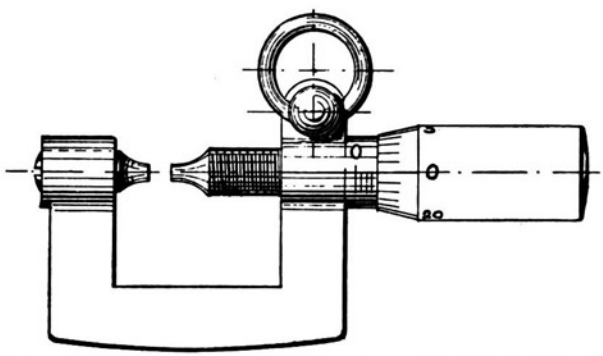

Fig. 36.—Small steel micrometer with G.M. thimble

shown in figs. 35 and 36 are recommended as the result of thorough tests. Fig. 35 has a German-silver frame fitted with a special milled friction nut (shown shaded) at the end of the thimble. There is no locking device on this tool, and the sample submitted showed an error slightly greater than half a thousandth of an inch in half an inch. The friction nut is silent, and is not actuated by means of a ratchet.

Fig. 36 in many points is better than the one above in that it has a steel frame, and has a locking device to some extent capable of taking up wear. Tests made on this instrument showed that in 0.6 in.—which is its maximum reading—as low an error as 2½-10,000ths was all that could be found. The greatest disadvantage of this instrument is the small size of its points, which renders more care necessary in taking measurements of comparatively large diameters. There is a very good design of micrometer used in the clock trade, and sold in Clerkenwell at a very low price. It has a brass frame and steel fittings, and is fitted with a ratchet stop, the important feature of this tool being that thousandths are read off a dial of large diameter by means of a pointer attached to the thimble. The advantage of this form of reading is that the divisions are so large that half- and quarter-thousandths are very easily determined.

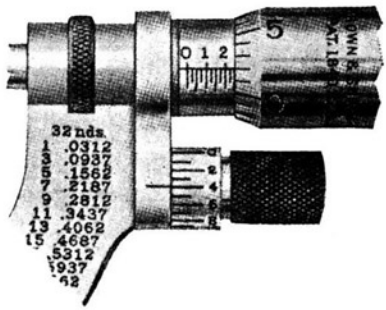

Fig. 37.—The Brown & Sharpe No. 24 micrometer, which has an auxiliary thimble to read ten-thousandths of an inch

Only brief reference can be made here to such forms of micrometer as the beam micrometer, in which there are measuring points capable of sliding along a beam and of being locked to it at stated intervals, the fine adjustment being performed by the usual 1 in. micrometer head attached to one of the points. This form, together with the micrometer sets, are for much larger work than usually falls to the lot of the small-power engineer. Micrometer heads have been successfully applied to such as surface gauges, and special tools for testing the truth of planer tables, lathes, gear wheels, and for similar purposes.

CHAPTER VI

HOW TO READ THE MICROMETER

THE majority of English and American micrometers read primarily in one-thousandths of an inch, though the increasing use of metric standards of measurement has made it necessary for nearly all modern engineering factories to have metric micrometers also available. Most British mechanics, however, have cultivated the habit of " thinking in thousandths of an inch," even when working to metric standards, and seem to prefer consulting tables of equivalents instead of risking possible confusion by changing over to the use of a metric micrometer. The use of thousandths of an inch as a standard of dimensions is extremely convenient in practice, and in certain classes of work it has been technically named a " mil," especially in electrical engineering, where the 1-1000th part of an inch is constantly used in measuring thicknesses of insulation and diameters of wires.

Although this is the unit of the micrometer, its thread is not a decimal thread—that is to say, the pitch or number of threads per inch is not a decimal fraction of an inch, such as 1000, 100, or 10. All modern micrometers intended to read in 1000ths of an inch are made with a screw of 40 threads per inch of length ; hence for one revolution of the screw the instrument opens or closes 1-40th in. Fig. 38 shows, in diagrammatic form, the section of a micrometer to familiarise you with the names of the parts that are graduated. The sleeve, which is in one with the frame, is threaded inside, and takes the screwed spindle A. On

the latter is fixed firmly the thimble C, which travels with the screw, but outside the sleeve. It is between the relative position of the edge S of the thimble and the external surface of the sleeve that the measurements are taken.

Fig. 39 shows the horizontal scale that is engraved along the outside of the sleeve. The small divisions correspond to the pitch of the thread, and hence are 1-40th in. apart. When the micrometer is closed up, and is measuring nothing, the edge of the thimble stands about over the left-hand long mark labelled 0, and when it is given one complete turn open it stands over the first short mark to the right of this, two revolutions the second mark, and so on. It must not be assumed that this scale is used to measure by in this manner, or in the same way as a rule would be used, but the scale is really used as a reference to indicate how many revolutions of the screw have been effected. Each revolution as recorded

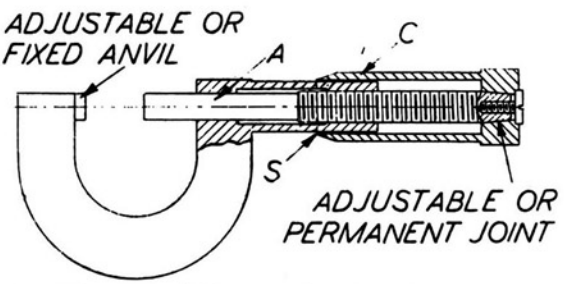

Fig. 38.—The essential parts of a standard type of micrometer caliper

by a small division, therefore, represents 1-40th in., which is 25-1000ths. Two revolutions, as shown by two marks, equal 50-1000ths, three revolutions 75-1000ths, and four 100-1000ths. As the last-named equals 1-10th in., it is emphasised by making it a long line and marking it 1 in the first case, and so on. Therefore each long line, occurring at every fourth small space records a tenth of an inch, and reads 1, 2, 3, 4, up to 10—10-10ths, of course, completing the

inch. By this scale, therefore, we can read 0, 25-1000ths, 50-1000ths, 75-1000ths, 1-10th, 125-1000ths, 150-1000ths, and so on.

Now, to determine the revolutions. Notice, in the first place, the horizontal line on the sleeve, which has been marked A in fig. 39. When the micrometer is closed a similar mark made at right angles to the edge of the thimble and engraved thereon stands exactly level with this mark and in

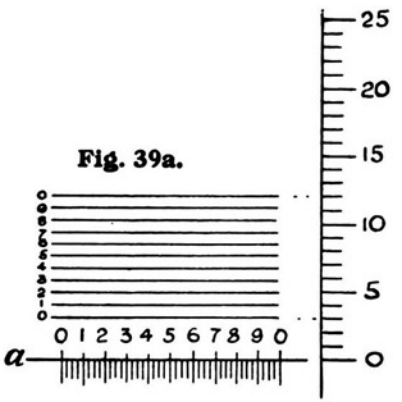

Fig. 39. Fig. 40.

Micrometer scales in their relative positions: Fig. 39, sleeve scale; Fig. 39a, vernier scale to read ten-thousandths; Fig. 40, thimble scale

alignment with it. This mark on the thimble is called the zero line, and it is usually marked with 0. Now fig. 40 shows a development of the scale, which is engraved equally all round the edge of the thimble, and which travels round with the screw past the horizontal line A. It will be noticed that there are 25 small divisions, therefore the 25 mark does not really occur, as it is the same as the zero line. One revolution being 25-1000ths, 1-25th of that, as indicated by the small divisions on the thimble passing the horizontal line on the sleeve, is 1-1000th in. It will now be seen that although the edge of the thimble may appear to stand exactly over, say, the first small mark on the sleeve, it is really the zero line

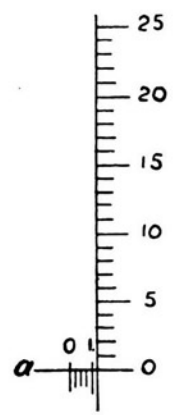

Fig. 41.—Set to $\frac{1}{8}$ in.

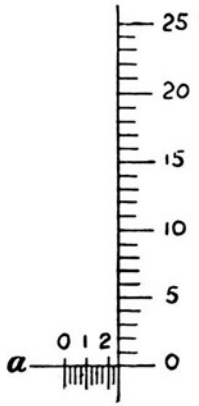

Fig. 42.—Set to $\frac{1}{4}$ in.

Fig. 43.—Set to $\frac{3}{8}$ in.

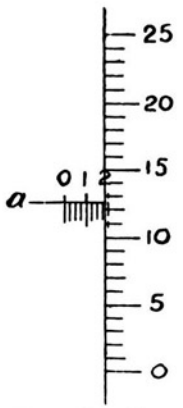

Fig. 44.—Set to 3-16ths in.

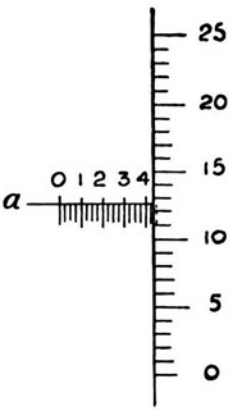

Fig. 45.—Set to 7-16ths in.

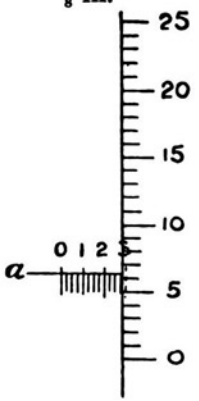

Fig. 46.—Set to 9-32nds in.

Diagrams of various micrometer settings

on the thimble coming round and coinciding with the horizontal line A on the sleeve that indicates exactly the number of revolutions and the number of parts of a revolution (that is, thousandths) which the micrometer has opened. For convenience in reading, each fifth small division (thousandths) on the thimble has a longer line, and is figured thus : 5, 10, 15, and so on.

Now notice the actual readings for several ordinary fractions. With the thimble edge standing over the fifth small mark on the sleeve and the zero on thimble in alignment with A (fig. 41), the gauge reads 125-1000ths or $\frac{1}{8}$ in. With the zero line the same, but thimble-edge over the tenth small line (fig. 42) 250-1000ths, or $\frac{1}{4}$ in.; Fig. 43 gives 375-1000ths, or $\frac{3}{8}$ in., and so on. Fig. 44 shows the reading for 3-16ths, the thimble scale being $12\frac{1}{2}$-1000ths beyond the seventh small mark on the sleeve. The latter is 175, and this plus $12\frac{1}{2}$ or 12.5, gives 187.5-1000ths, which is the equivalent of 3-16ths. Next, fig. 45 shows the indication on the thimble to be 12-5 beyond 425 on the sleeve, which equals 437.5-1000ths, the equivalent of 7-16ths. Notice the position of the thimble scale in fig. 46; here the index line A stands just beyond the sixth division on the thimble, about one-fifth or 0.2 of a division. Here the thimble, then, is 6.2, which, added to the sleeve reading, 275, makes 281.2-1000ths, or 9-32nds in. Fig. 47 gives the reading for No. 0 B.A., which, in English measure, is 0.236, or 236-1000ths. The thimble scale stands exactly eleven divisions beyond 225 on the sleeve. To be quite exact, it should be rather over one-fifth of a division beyond the eleven, because the exact size of No. 0 B.A. is 6 millimetres, which is 0.23622. But 236 is quite near enough for practice. Fig. 48 is the reading for No. 5 B.A., the equivalent of which is 0.126, or 1-1000th in. over $\frac{1}{8}$ in. Notice that the thimble indicates one division beyond the zero, which would record, if level with the line A, exactly $\frac{1}{8}$ in., as shown in fig. 41.

Extra Fine Reading

In ordinary engineering practice, it is generally sufficiently accurate to work to the third decimal place, or in other words, to the nearest thousandth of an inch. But some fractional measurements can only be expressed correctly by four (or in some cases, even five) places of decimals; and if these are to be accurately measured, something finer than the ordinary

graduations of the micrometer thimble are presumably necessary. An odd half or quarter of a division can be estimated sufficiently accurately by eye for most practical purposes, but in cases where it is necessary to indicate ten-thousandths of an inch, the micrometer can be equipped with a vernier scale engraved around the circumference of

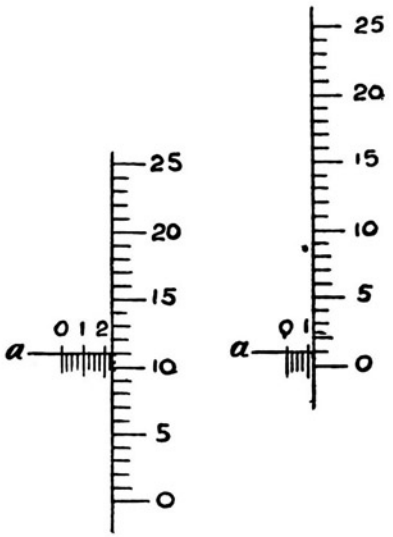

Fig. 47.—Set to No. 0 B.A. (0.236 in.)

Fig. 48.—Set to No. 5 B.A. (0.126 in.)

Further diagrams of micrometer settings

the fixed sleeve, the divisions being spaced so that ten of them are equal to nine of the divisions on the thimble.

The zero on the vernier stands three thimble divisions above the line A, and thence are numbered 1, 2, 3, up to 10. According to which number line of the vernier stands flush with a division on the thimble, there are that many 1-10,000ths of an inch beyond the ordinary reading of the micrometer.

Metric micrometers are made with a screw having a pitch of $\frac{1}{2}$ millimetre. There are, therefore, nearly 51 threads to

an inch, which makes it a much finer thread than that of the English. The sleeve scale is set out in millimetres, having every fifth one a longer line stamped 5, 10, etc., up to 25, which is the usual limit of the size corresponding to the 1 in. English. The thimble is, therefore, revolved twice to complete a small or millimetre mark on the sleeve, a point which must be carefully noted in reading, otherwise one is likely to

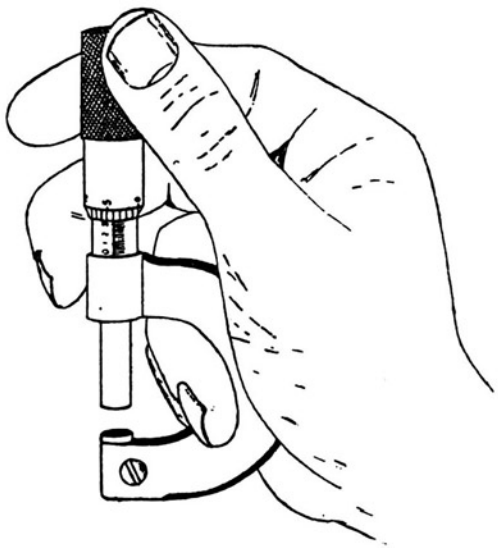

Fig. 49.—How to hold a micrometer to measure work held in the other hand

get a $\frac{1}{2}$ millimetre out. The thimble is divided equally out into 50 divisions, every fifth of which is made with a longer mark and stamped. A fiftieth part of $\frac{1}{2}$ millimetre is a hundredth of a millimetre, which is the usual unit of these micrometers; 1-100th mm. equals 0.0003937, or nearly 4-10,000ths, which is less than a half-thousandth of an inch. These are therefore much finer measuring instruments than English micrometers.

Unless he is using a micrometer holder, an expert generally holds a 1 in. micrometer as follows. The top joint of the third finger of the right hand is hooked into the horse-shoe frame

of the tool, and thus holds the tool with the thimble upward (fig. 49). The milled end of the thimble is then operated upon by the thumb and first finger of the same hand. It is not easy to describe this, but with a little practice it will come easy to carry it out by following these directions. Of course, this can only be done in measuring small work, as the presence of the little finger would get in the way of anything large, such as of $\frac{1}{8}$ or 1 in. diameter. The idea does not well apply to small micrometers, such as measure up to $\frac{1}{2}$ in. only as, of course, they are too protracted in the frame even to take the little finger. Some makers, therefore, affix a ring upon the outside of the horse-shoe frame, on the underside near to the thimble, which is then in convenient position to take the second finger, hooked in as described. This attachment is applied to 1 in. micrometers also.

In gauging by the micrometer, the work must be gripped by the measuring points. It should be obvious that, if it can be moved at all between the measuring points, the instrument is recording a greater size than the job actually is. The extent to which the work is gripped, to give accurate size, is largely a question of experience in micrometer use, and, although ratchet and friction stops are provided as aids to equalising this grip, the best results are obtained by a careful user, familiar with his micrometer, and operating it by its thimble. The pressure applied should not be enough in any way to deform the tool, but just enough to make good the difference between an outside size and the space into which it will just go, taking into consideration the shape of the surfaces measured.

CHAPTER VII

SOME EXAMPLES OF MODERN MICROMETERS

THIS book would not be complete without showing a few examples of modern micrometers, particularly those representing British manufacturing practice, which is now recognised as being of the very highest class. We are indebted to Messrs. Moore & Wright (Sheffield) Limited, for the illustrations in this chapter, which show some selections from their wide range of productions.

In fig. 50 is given a sectional drawing showing the main features incorporated in the micrometers of this firm's manufacture. The spindle and screw are in one piece, of special alloy steel, almost impervious to wear. The thread of the screw is ground out of the solid bar, after hardening, giving an exceptional degree of accuracy. The shape of the screw thread should be noted. Since the accuracy and long life of a screw depend on the accuracy of the flanks of the thread, contact with both the crest and the bottom of the thread is eliminated. The clearance thus provided enables lubricating oil to be retained, and also provides a place of escape for any small pieces of grit or dirt which may find their way into the screw. The shapes of the threads on the screw and nut are shown in the enlarged detail drawing in fig. 50. The large screw diameter, giving a larger thread wearing area, and the extensive range of adjustment on the thimble and spindle are other points of advantage in this design.

It is of great importance that the faces of the spindle and the anvil should be absolutely flat. This condition is secured

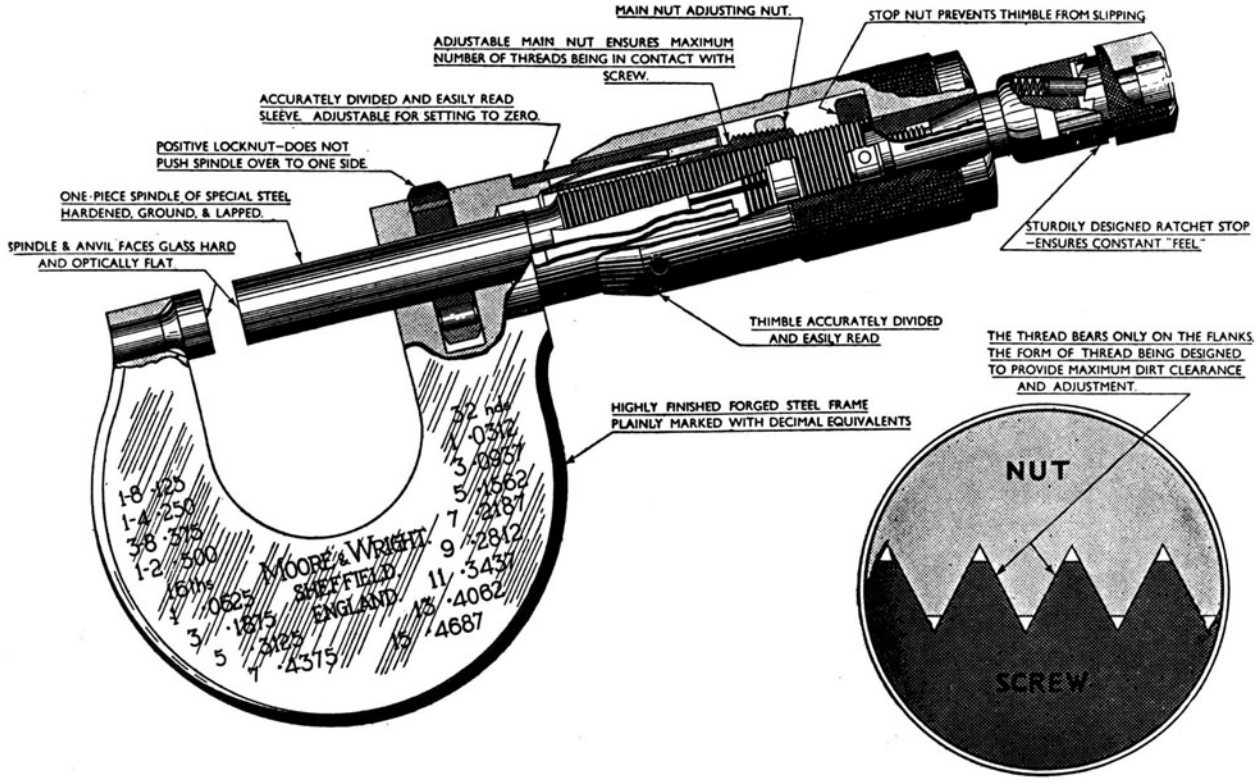
MAIN NUT ADJUSTING NUT.
STOP NUT PREVENTS THIMBLE FROM SLIPPING
ADJUSTABLE MAIN NUT ENSURES MAXIMUM NUMBER OF THREADS BEING IN CONTACT WITH SCREW.
ACCURATELY DIVIDED AND EASILY READ SLEEVE. ADJUSTABLE FOR SETTING TO ZERO.
POSITIVE LOCKNUT—DOES NOT PUSH SPINDLE OVER TO ONE SIDE.
ONE-PIECE SPINDLE OF SPECIAL STEEL HARDENED, GROUND, & LAPPED.
SPINDLE & ANVIL FACES GLASS HARD AND OPTICALLY FLAT.
STURDILY DESIGNED RATCHET STOP —ENSURES CONSTANT "FEEL."
THIMBLE ACCURATELY DIVIDED AND EASILY READ
THE THREAD BEARS ONLY ON THE FLANKS. THE FORM OF THREAD BEING DESIGNED TO PROVIDE MAXIMUM DIRT CLEARANCE AND ADJUSTMENT.
HIGHLY FINISHED FORGED STEEL FRAME PLAINLY MARKED WITH DECIMAL EQUIVALENTS
MOORE & WRIGHT SHEFFIELD ENGLAND
NUT
SCREW

Fig. 50.—Sectional drawing showing internal construction of an "M. & W." precision micrometer. Enlarged detail view shows the shape of the thread used.

in the M. & W. instruments by an optical test. An optical test piece, placed against the spindle or anvil face, becomes distorted if the face is in the smallest degree not flat, coloured

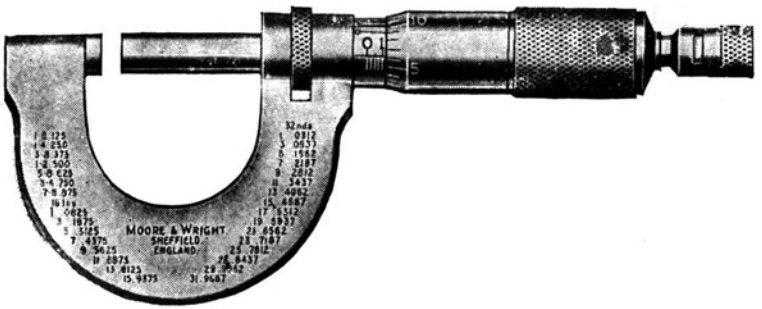

Fig. 51.—"M. & W." precision micrometer reading in ten-thousandths

bands being shown on the test piece by the method of light interference. The number of coloured bands which appear is a measure of the inequality of the surface. No face is passed as flat which shows more than one complete interference band. This is equivalent to an accuracy of 10-millionths of an inch.

A study of the drawing in fig. 50 will show the other features of careful design which are characteristics of this

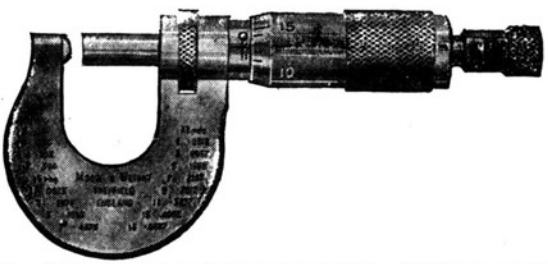

Fig. 52.—Micrometer for measuring thickness of tubes

tool. It may be mentioned that, for the purposes of class or workshop instruction, a large wall-chart of this drawing may be obtained free from the makers. Fig. 51 shows the external appearance of an M. & W. micrometer, reading in 10,000ths by a vernier.

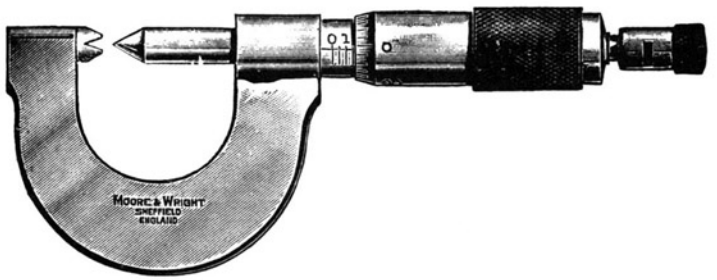

Fig. 53.—Micrometer for measuring the pitch diameter of screw threads

Micrometers are made in various patterns to suit special requirements. In fig. 52, for example, is shown a tube micrometer, in which the frame is cut away to permit its entry into a tube, the thickness of the wall of which is to be measured. In this type of instrument a ball anvil is substituted for the flat anvil. This micrometer will enter a 5-16th in. hole.

For the measurement of the pitch diameter of screw

Fig. 54.—Micrometer for measuring the thickness of work in progress on a surface grinder

threads another type of micrometer is made, as shown in fig. 53. In this type the anvil has a V-recess and the spindle end is pointed. Only the angle of the point and the sides of the V-recess come into contact with the thread. Thus the

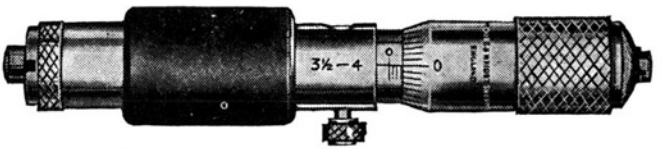

Fig. 55.—Tubular micrometer for measuring internal diameters

pitch diameter is measured, *i.e.* the full diameter less the depth of one thread.

Another useful application of the micrometer principle is shown in fig. 54. This is intended for use on a surface grinder for measuring the thickness of the work while it is still on the

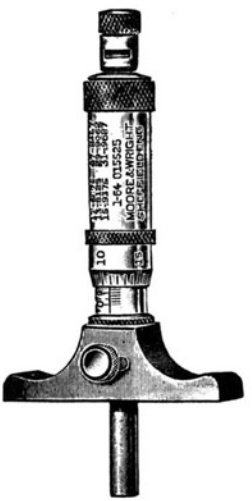

Fig. 56.—A micrometer depth gauge

machine. It is fitted with a hardened-steel plate on the base, and the end of the spindle is slightly rounded. It is graduated in thousandths, and has a capacity of one inch.

The measurement of internal diameters is another work-

shop requirement to which the micrometer can usefully be applied. An inside micrometer is shown in fig. 55. The body of the instrument is made of tubing, giving both strength and lightness, and is fitted with a fibre insulating sleeve, to prevent expansion due to heat of the user's hand. The anvils are ground to a radius, so that the micrometer may be used for measuring either flat or curved surfaces.

Still another form of micrometer is the depth gauge, illustrated in fig. 56, which reads up to 1 in. The uses of this will be obvious to the practical mechanic, but these examples are intended to show how the principle of exact measurement by the micrometer can be applied to almost any kind of workshop need.

The present generation has seen the exactitude of machine-shop and tool-room methods develop out of all knowledge. The introduction of limit gauges, of press tools and jigs, of milling and grinding machines, and of other mass production equipment has made exact measurement to close limits a vital necessity in the modern workshop. The micrometer in its various forms enables this precision to be attained, and it is hoped therefore that this handbook may assist in the better understanding of the principles which govern both the construction and use of this valuable workshop and laboratory accessory.

CHAPTER VIII

THE USE OF MEASURING INSTRUMENTS

IT has already been stated that in order to obtain the most accurate results of which measuring instruments are capable, a certain amount of skill must be used in applying them; this applies to all kinds of calipers, slide gauges and micrometers, whatever may be their special purpose or design. The acquiring of such skill is one of the most important items in the education of the engineering craftsman, and is of paramount importance in practical work, whether it be machining, fitting and erection, or examination and testing of machines or components. It depends to a great extent on developing a delicate and exact sense of touch, together with learning correct methods of holding and applying the instrument to the work.

Calipers

Calipers, whether of the firm joint or spring type, demand great care in use, as they are all more or less elastic and can be forced over or into work which is a good deal oversize or undersize, as the case may be. For sizing work accurately, calipers should be held in such a way that the slightest variation in the friction of the points, as they pass over the surface of the work, can easily be felt; and when one piece of work is being compared with another, or with a master gauge, a close agreement in the friction of the caliper points on the two pieces will indicate that they are within very small limits of identical size. A really skilful user of calipers can detect a difference of one-thousandth of an

inch in the diameters of two small specimens of work. In larger pieces, accuracy is generally more difficult, as it is not so easy to be quite sure that the instrument is presented exactly square with the work ; also its weight is greater, thus impairing sensitivity of touch. The same considerations largely apply to the use of micrometers and slide gauges.

When using outside calipers, they should be held at or very close to the pivot joint, between the thumb and finger of the right hand, and allowed to centre themselves as they pass over the work. For the utmost sensitivity of touch, one leg of the calipers may be steadied by the left hand, and the point held stationary, while the other point is rocked over the maximum diameter of the work (fig. 57). By this

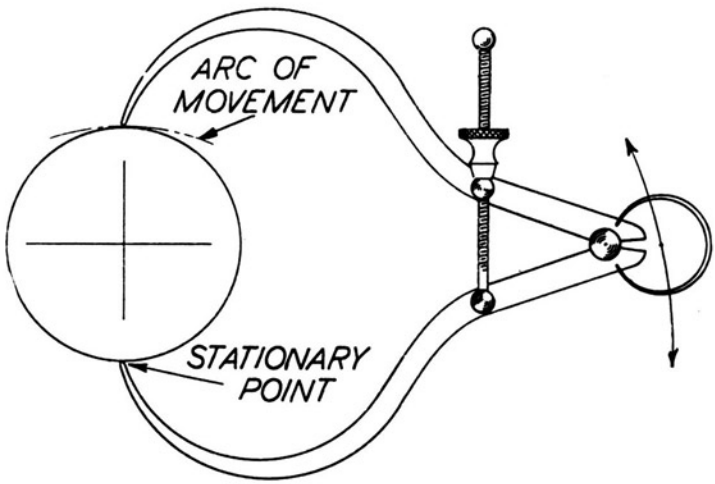

Fig. 57.—Method of using outside calipers, recommended for accurate work

means, the operator's sense of touch is assisted, as the length of arc over which the moving point makes contact with the work is a clear indication of the amount of oversize error. The ultimate accuracy is obtained when there is only a mere " point contact " under these conditions.

In fig. 58 is shown the method of using inside calipers to determine the size of a hole. The calipers should be loosely

held at the joint or bow end, between the thumb and finger. Although the points may be disposed in any place across the axis of the hole, it will generally be found most convenient to set one point vertically over the other as shown, and the instrument should be presented parallel with the axis of the hole. With the lower point in contact with one side of the hole, the low end is moved up and down so that the upper point describes an arc about the pivot centre formed by the stationary lower point. As in the case of outside calipers, the shortness of the arc of contact, and the lightness of "feel," decide the accuracy of gauging by this method.

One advantage of spring calipers for inside measurements is that they can be used to measure a recess, or a hole of larger diameter behind a smaller "bottle-neck," as the calipers can be closed by pressing the legs together against the spring, enabling them to be inserted or withdrawn without altering the caliper setting as decided by the adjusting nut.

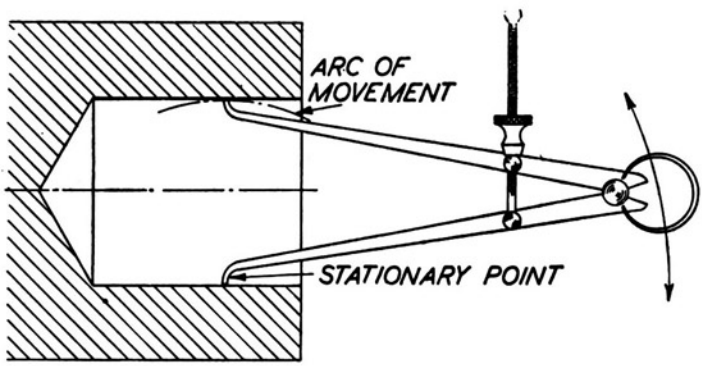

Fig. 58.—Method of using inside calipers, recommended for accurate work. (Note : It is most important to ascertain, by swinging the calipers in the cross plane also, that they span the maximum diameter of the hole)

To facilitate the adjustment of inside calipers to exact size, when working to holes of small dimensions, they may be used in conjunction with a micrometer, as shown in fig. 59. In this case, the micrometer is set to the exact size required, and used as a reference gauge, the calipers being

adjusted in exactly the same way as when measuring the size of a hole, as just described. Alternatively, the size of an existing hole may be exactly determined by measuring it with the calipers, and then transferring the latter, at the same setting, to the micrometer ; in this case, the latter is adjusted to the same "feel" as the work being tested, and the size can then be read on the micrometer index.

It would be possible to set outside calipers to an internal micrometer in the same way, but it is usually more convenient to use an outside micrometer directly on the work, when one is available.

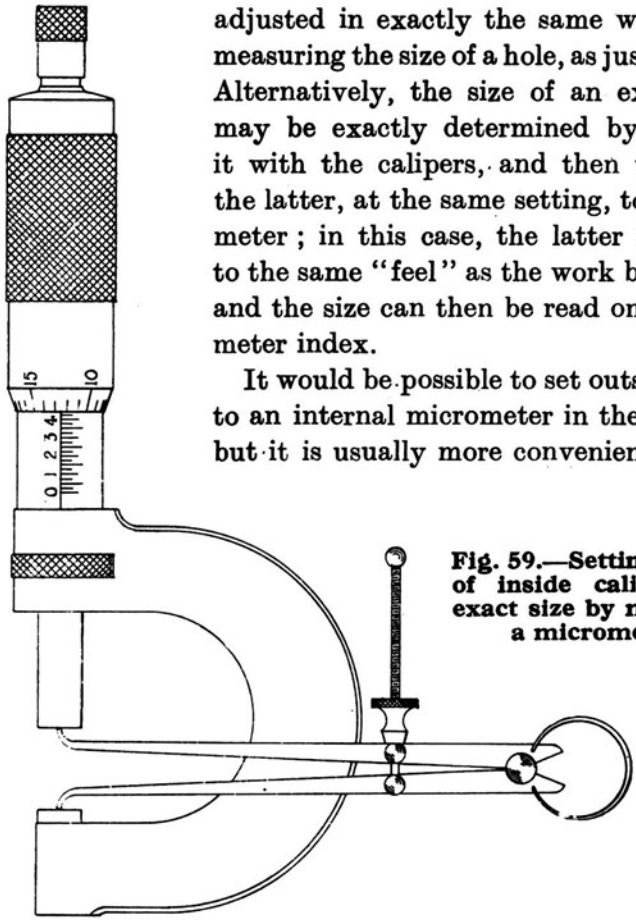

Fig. 59.—Setting a pair of inside calipers to exact size by means of a micrometer

Slide Gauges

Slide gauges are generally used by closing them on to the work and reading the size from the vernier scale (or opening them out to the work, for internal gauging). In cases where it is found preferable to " pre-set " the gauge to a given size, or to use it as a comparator, great care is necessary in presenting the instrument to the work, to avoid straining the jaws. These have not the same elasticity as caliper

points, which are not easily injured by springing them over the work. Slide gauges should never be used on work while it is rotating in the lathe, as quite apart from the risk of wearing or damaging the jaws by rubbing friction, there is a distinct possibility that they may seize or jam on the work, and become literally wrapped round it, and thus completely destroyed. This caution applies with even greater force to micrometers.

Slide gauges may be used in the same way as micrometers to facilitate accurate setting of calipers or other comparator gauges.

Choice of a Micrometer

Under present conditions, it may be fairly stated that a micrometer is an indispensable item of every engineer's tool kit. The most useful size is that reading from 0 to 1 in., which will cover by far the majority of ordinary requirements, but of course even greater scope is obtained by a larger micrometer with interchangeable anvils to enable it to be set to different sizes. Owing to the general handiness of the compact little one-inch " mike," however, it is almost invariably chosen as the mechanic's daily companion.

When only occasional measurements, and most of them only comparative at that, have to be made, the cheapest type of micrometer will be found quite suitable ; but the engineering apprentice, who is likely to need a micrometer for regular use over a period of years, is advised to buy the best micrometer he can possibly afford. And when the micrometer has been bought, do not keep it hidden away in a case, or merely to look at, but *use it*. Measure anything and everything at the least provocation—screws, drills, wire, paper, and even hair. To many people this may seen like merely playing with the instrument, but in actual fact it helps you to acquire practice in handling and using it and, what is even more important, cultivates a habit of accuracy and " thinking in thous."

For the quick production of accurate work in the lathe, the micrometer is well-nigh indispensable and should be used for every job within its capacity. It will tell at a glance whether the lathe is cutting parallel or taper, and how closely it is approaching the correct size. Actually, the micrometer is a much more rapid means of measuring than any other tool, and by its constant use the worker will quickly improve the quality of his work, and reduce the number of scrapped jobs, through the elimination of guesswork.

In other classes of machining, and also on fitting work, there is perhaps rather less scope for the use of the micrometer, but it is just as indispensable for really accurate work, and will simplify and improve the precision of many a difficult job. In the fitting of split bearings, for instance, the exact amount of running clearance at any point can be ascertained by inserting lead wires between the shaft and bearing, and bolting the latter down tightly. It is then again dismantled and the lead wires taken out, having been squeezed out to a thickness which represents the clearance and is readily measured by the micrometer. The filing of work to exact shapes and sizes is also very much facilitated by using the micrometer constantly to check the progress of the work.

In modern engineering practice, certain standards have been established by means of which the fit of shafts, bushes, etc., to any degree of tightness required can be ascertained and assured without the necessity for hand fitting or " cut-and-try " methods. By the aid of these standards, together with the intelligent use of measuring instruments, a machinist can, without difficulty, bore out a bush or a housing which will be either a running or driving fit, as required, on a shaft which may be thousands of miles away.

Care of Micrometers

It will be evident to every engineer that a micrometer should be kept clean and never, in any circumstances, be

allowed to go rusty. The use of any form of abrasive in cleaning a micrometer, however, must be avoided like the plague, and if by any mischance rust should make its appearance, it is better to put up with the discoloration or pitting than to attempt to remove it by means of emery cloth. Rust does not necessarily affect the accuracy of a micrometer, so long as it does not eat into the faces of the anvil or the spindle, or jam the screw thread.

To clean the contact faces of the anvil and spindle, they should be opened a little way and a slip of absorbent paper inserted between them. They are then closed on to the paper sufficiently to grip it, and then released about half-a-thousandth of an inch. It will now be possible to pull the paper out, at the same time removing any dirt which may have adhered to the faces. The use of a little thin oil on the micrometer screw is advisable, but excess oil only encourages the collection of dust ; this at all costs must be scrupulously avoided, especially if the instrument is used in a factory or locality where grit or other abrasive particles are likely to be carried in the air or on the worker's clothes.

Adjustment of micrometers is an operation which is best left alone by the ordinary worker, unless it is absolutely necessary. An error of one or two thousandths, if it is known, does not in any way affect the capability of the instrument to do accurate work, as it can be allowed for in reading the measurement. Some micrometers are designed so as to be adjusted from the anvil end, while others have the spindle so attached to the thimble that their relative positions can be adjusted. The method of adjusting any particular micrometer is always given in the maker's leaflet or book of instructions.

Local or variable errors in the micrometer, caused by wear or initial faults in manufacture, are quite ineradicable, and the only alternative to accepting and allowing for them is to discard the micrometer and buy one of guaranteed accuracy.